



**Department of Environment, and
Workplace Safety and Health**

**Environmental Management Division
Environmental Management Services**

Aquatic Impact Assessment of the Sherridon Mine

**Environmental Standards and Studies
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AQUATIC IMPACT ASSESSMENT OF THE SHERRIDON MINE

**A.E. Beck,
Water Standards and Studies Section,
Environmental Management Services Branch,
Environmental Management Division.**

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ABSTRACT

During June, 1982 Water Standards and Studies conducted an investigation in the Sherridon area in order to assess the impact of the abandoned Sherridon mine and mill tailings upon lakes in the vicinity. Leachate and other materials emanating from the tailings site were found to have altered Camp Lake to the point where conditions were hostile to most macroscopic aquatic life forms. Discharges of metals and highly acidic waters from Camp Lake had degraded Cold Lake water quality and impacted upon its sediments and fish distribution. Continued discharges from Camp Lake were expected to further aggravate deteriorating conditions. Cold Lake, however, did constitute an acceptable source of potable water supply. Sherlett Lake, located upstream of the tailings site, constituted an excellent source of potable water supply.

SUMMARY

A major copper-zinc mining and milling complex, now abandoned, had been located in the Sherridon area approximately 65 kilometers northeast of Flin Flon. The proximity of the tailings has prompted concerns among residents of the adjacent communities of Cold Lake and Sherridon regarding the integrity of local potable water supply sources. The community of Cold Lake derives its supply from Cold Lake and the community of Sherridon from Sherlett Lake. Concerns were also expressed regarding the impact of tailings drainage upon fish in receiving waters. Responding to these concerns, Water Standards and Studies Section conducted an investigation of the area.

The study area was limited to lakes in the immediate watershed of the tailings site. These included Sherlett Lake (an upstream control), Camp Lake (adjacent to which the tailings are located), and the downstream waters of Cold Lake (the proximal bay of Kississing Lake). Scope of the study was focused on water physicochemistry, sediment metal concentrations and metal levels in the muscle tissue of resident fish species.

Anthropogenic impacts upon Sherlett Lake were not detected. The lake was considered meso-oligotrophic in character and both water physicochemistry and sediment metal concentrations were typical of the geophysical setting. Metal levels in resident fish species were similar to those of Gods Lake, a system generally considered pristine. Sherlett Lake was found to constitute an excellent source of potable water supply.

Camp Lake was severely impacted by leachate and other materials emanating from the tailings site. Symptoms of severe degradation included depressed pH and alkalinity, elevated concentrations of copper and zinc and the virtual absence of macroscopic organisms. The low pH and high concentrations of copper and zinc present in the water column were probably synergistically toxic to fish. The aggregate of all physicochemical factors provided an environment hostile to most macroscopic aquatic life forms.

A small area of Cold Lake immediately downstream of the Camp Lake outfall also showed considerable water quality degradation which again included high zinc concentrations and depressed pH and alkalinity. Although significant iron loading to sediments was observed, the acidic nature of Camp Lake discharges appeared to have leached and transported most other sedimented metals from the immediate area. Conditions were not considered acutely toxic to aquatic biota. However, it was recognized that chronically the plankton and benthic populations could be detrimentally affected and that highly motile organisms such as fish might demonstrate strong avoidance behaviour.

The area of Cold Lake adjacent to the community suffered a lesser degree of water column degradation. Water column zinc concentrations were still significantly greater than background but factors such as pH were not significantly different from Sherlett Lake. The aggregate water quality was considered acceptable for a source of potable water supply. An excellent water quality rating was denied on the basis of aesthetic considerations such as

turbidity. Values were within the maximum acceptable range instead of the optimum category. Most sediment metal concentrations, however, were significantly greater in this area than in the immediate vicinity of the Camp Lake outfall. It was thought that the acidic discharges had mobilized sedimented metals from the outfall area and then resedimented them outwards as pH values recovered. This was termed the "wave effect" in an allusion to the groundswell appearance of the observed concentrations. Levels encountered were not considered acutely toxic to benthic organisms.

The Cold Lake fish population appeared considerably reduced in number from the Kissinging Lake average. This impact was attributed to selective avoidance of Cold Lake waters which received Camp Lake discharges. Muscle tissue zinc concentrations alone were significantly elevated over background. This, however, could not definitely be proven an effect of zinc loadings via Camp Lake discharges.

It was recognized that continued discharges from Camp Lake would further aggravate deleterious impacts upon the water column, sediments and fish of Cold Lake.

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INTRODUCTION

The Sherridon copper-zinc mine ($55^{\circ} 08'$, $101^{\circ} 05'$) operated from 1928 to 1951. A total of 7,737,936 tonnes of pyritic ores were milled, producing 166,093 tonnes of copper and 135,108 tonnes of 50% zinc concentrate (Mineral Resources Branch, 1978). The now abandoned mine and tailings site is situated along the shoreline of Camp Lake, a tributary to Kississing (Cold) Lake ($55^{\circ} 10'$, $101^{\circ} 20'$). Two small communities, Cold Lake and Sherridon, are located within 2 kilometres of the tailings area. Each community utilizes the adjacent waterbodies of Cold Lake and Sherlett Lake, respectively, as sources of potable water supply. Additionally, Kississing Lake supports a substantial sport and commercial fishery.

Concerns have recently been expressed regarding possible contamination of local water supplies and potential degradation of fish habitat. Residents of Sherridon in particular were concerned that prevailing westerly winds may have transported metal laden dust particles two kilometres eastward to Sherlett Lake, the community's source of water supply. Residents of Cold Lake were concerned that metals may have leached from the tailings, dispersed through Camp Lake and subsequently contaminated their water supply located approximately 2 kilometres downstream of the Camp Lake outlet. Both residents and non residents utilizing the fish resources of the area were concerned that fish habitat may have been degraded by Camp Lake

drainage. Responding to these concerns, Water Standards and Studies Section conducted a study of the area during June 17-24, 1982. The primary objectives of the study were threefold:

1. To assess the water quality of Sherlett, Camp and Cold Lakes;
2. To determine whether heavy metals and acid producing materials were leaching from the tailings disposal site and were draining to Cold Lake;
3. To assess the impact of Camp Lake drainage on Cold Lake.

DESCRIPTION OF AREA

The study area lies approximately 640 kilometres north-northwest of Winnipeg and is accessible by CN railway and charter air service (Figure 1). Physiographically, the area falls within the Precambrian Drift Plain subregion (Weir, 1960). The topography is rolling to rugged with frequent rock outcrops. Glacial drift materials, peat deposits, podzols and grey wooded are the dominant soil types encountered. Mixed stands of aspen, birch and spruce dominate the vegetation.

Sherlett Lake

Sherlett Lake ($55^{\circ} 08'$, $101^{\circ} 04'$) is a relatively small, irregularly shaped lake with a surface area of some 1.80 square kilometres (Figure 1). It is comprised of three basins and is oriented in a north-south direction. The maximum depth appears to be in excess of 7.0 metres. Detailed morphometric data is currently unavailable.

Sherlett Lake receives drainage from approximately 107 square kilometres. The bulk of this inflow enters the northernmost basin via four small, unnamed creeks. Outflow is via Sherlett Creek in the southernmost basin's western end (Figure 1). Water levels and rate of outflow are regulated by a dam at the lake outlet. The dam is constructed of waste rock and other materials

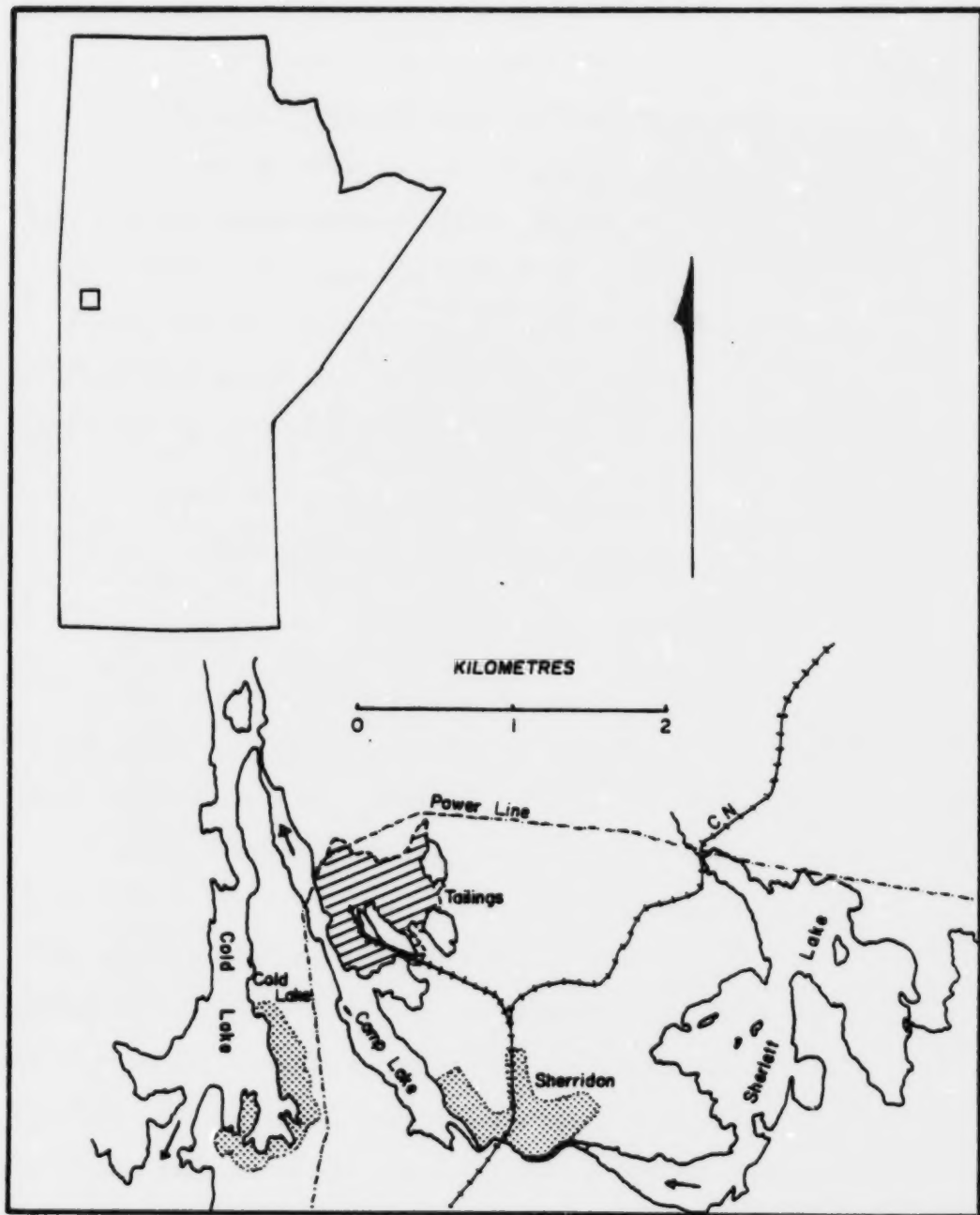


Figure 1: Overview of the Study Area

from the Sherridon mine and has a central concrete spillway. Flows thru the spillway were estimated on June 17, 1982 at 0.02 cubic metres per second.

The topography of the shoreline is highly irregular and varies from steep outcrops to flat bog like areas. Gneissic outcrops and rock rubble materials predominate. Bog and associated peat form a significant portion of shoreline only in the north and central basins. Shallow depths of glacial derived silts overlying gently rising gneissic bedrock are a common shoreline development in the southernmost basin.

The geology of the area is exceedingly complex and has been described by Davies et al (1962).

Sherlett Lake serves as the source of water supply for the nearby community of Sherridon. Area residents conduct minor boating and angling activities on the lake. Additionally, at least some of the local youngsters consider the southernmost basin an excellent swimming pool.

Camp Lake

Camp Lake (55° 08, 101° 06') is also a relatively small lake with a surface area of approximately 0.63 square kilometres. Approximately 2.75 kilometres long, it is a narrow lake oriented in a northwest-southeast direction (Figure 1). The maximum depth appears to be in excess of 9.0 metres. Like Sherlett, detailed morphometric data is currently unavailable.

The bulk (approximately 107 km^2) of Camp Lake's total watershed (approximately 113 km^2) delivers runoff through Sherlett Lake via 0.2 kilometre long Sherlett Creek. However, runoff and seepage generated from the tailings area are of particular interest to this study. Because the tailings area is contained entirely within the Camp Lake immediate watershed and since it both abuts and drains toward the lake, approximately 95,000 cubic metres * of water may annually enter Camp Lake directly from the tailings area. Camp Lake exits at the northern end of the lake.

Water levels and rate of outflow are partially regulated by a weir at the lake outlet. Apparently constructed during operation of the Sherridon mill, much of the original wooden structure has greatly deteriorated in the 31 year interim since site closure. However, original timbers still remaining have obstructed passage of floating trees and similar debris. This aggregate now serves to restrict outflows. Flows through the weir appeared to be somewhat greater than at the Sherlett Lake outfall, but could not be accurately estimated at the time of survey due to the great irregularity of the stream bed.

* Because of tailings surface compaction and the slope of the area, perhaps up to 50% of the 0.432 metre annual precipitation (Weir, 1961) may not be lost to ground infiltration and evaporation. Thus runoff = $440,000 \text{ m}^2 \times 0.432 \text{ m} \times 0.50 = 95,040 \text{ m}^3$ (extrapolated from Buckman and Brady, 1960).

Approximately 85% of Camp Lake shoreline is characterized by a climax spruce forest community overlying moderate to steeply rising gneissic bedrock. Thus most of the shoreline consists of consolidated material which drops off sharply from the waters edge. The remaining 15% of shoreline consists of mine waste rock and tailings. The tailings materials are unconsolidated and runoff from the pile has created an extensive underwater alluvial fan. Rust red discoloration of all materials below the high water line is a distinctive feature of the entire Camp Lake shoreline.

Kississing Lake Redwood Lodge, located at the south-east end of the lake, appears to be the sole current user of Camp Lake. The lodge maintains several boats on the lake for transport of guests to the outlet. Additionally, the lodge draws water for sanitary purposes directly from the lake.

Cold Lake

Cold Lake ($55^{\circ} 08'$, $101^{\circ} 07'$) is properly the easternmost bay of Kississing Lake. Approximately 8.2 kilometres long, it is a narrow bay oriented in a north-south direction (Figure 1). The maximum depth encountered during the present study was 9.6 metres, near the community of Cold Lake. A contour map of Kississing Lake depths, including the Cold Lake area, is presented in Schlick (1977).

Cold Lake receives drainage from approximately 172 square kilometres, 66% of which is received via Camp Lake. Apart from periods when drainage from the remainder of Kississing Lake's watershed may cause a backflow of lake waters into the Cold Lake area, the bulk of inflows to Cold Lake appear to originate with Camp Lake discharges. Seven of the influent streams to Cold Lake are intermittent and, excepting the Camp Lake outfall, only Bess Creek (at the south end of Cold Lake) contributes a significant volume of discharge. A faint rust red discoloration of approximately 1.2 kilometres of the proximal shoreline provides physical evidence of the flow of Camp Lake discharges towards the community of Cold Lake and the bay's outlet to Kississing Lake proper.

The shoreline of Cold Lake is topographically similar to that of Sherlett Lake. It is highly irregular and varies from predominating gneissic outcrops to a few flat boglike areas. A climax spruce forest community occupies much of the shoreline, although mixed stands, including deciduous trees, are common near the village of Cold Lake. The village of Cold Lake itself is a significant feature as buildings and the deforested area extend along more than 1.0 kilometre of shoreline.

Cold Lake serves several purposes for both local residents and visitors to the communities of Sherridon and Cold Lake. Primary among these uses is the fact that the lake serves as the source of water supply for the community of Cold Lake. Vitally important for both nearby communities, the lake also serves as a transportation focal point. A seaplane base provides rapid transport to the outside world. Area residents maintain boats on

the lakefront for transportation to outlying areas of Kississing and other directly accessible waterbodies. The lake is used for commercial fishing, trapping, hunting, angling and freighting of supplies from the Flin Flon road end. Additionally, both Sharron's Outfitting Service (Cold Lake) and Kississing Lake Redwood Lodge (Camp Lake) maintain waterfront boats for transport of guests. Recreational activities such as angling and swimming apparently occur to a limited degree.

Tailings Disposal Area

The tailings disposal area is located immediately adjacent to the mid-eastern shoreline of Camp Lake (Figure 1). The site encompasses an area of approximately 44 hectares and measures 1.0 x 0.8 kilometres (maximum dimensions). The south western one-third of the site is sloped towards and presumably drains directly to Camp Lake. Runoff from the rest of the site appears to be temporarily impounded in three ponds (Trap Lake, Wood Lake and an unnamed pond) along the eastern perimeter of the tailings area. These ponds discharge to Camp Lake via a system of eroded channels and deteriorated culverts.

The surface of the tailings appears well compacted and fairly impervious to water.

SUMMARY OF MINE AND MILL OPERATIONS*

The original discovery was made in 1922 by P. Sherlett. Shortly thereafter, C. W. Sherritt and R. Madole made a second discovery and staked a number of claims. A series of claim acquisitions and (claim) group optionings culminated in Nipissing Mines Company conducting exploratory drilling on the (by then) Sherritt-Gordon group property during the winter of 1925/26. This work indicated some 308,000 tonnes of ore averaging 2.86% copper and 3.3% zinc. A rapid series of option acquisitions and releases involving several companies then followed. No further active exploration or development of the property occurred until Sherritt Gordon Mines Limited was incorporated in July, 1927. Two mine shafts were sunk in 1928 and operations continued until the depressed markets of 1932 forced suspension. Production resumed in 1937 and continued until exhaustion of ore reserves in September, 1951.

The ore body was located along the northeastern shore of Camp Lake approximately 65 km northeast of Flin Flon. The ore consisted of relatively coarse-grained metallic sulphides. Pyrite was most abundant and was associated with decreasing amounts of pyrrhotite, chalcopyrite and sphalerite. Cubanite and arsenopyrite were rare.

* Summarized from Mineral Resources Branch, 1978.

During the life of the operation, a total of 7,737,936 tonnes of ore were milled. The milling yielded 166,093 tonnes of copper and 135,108 tonnes of 50% zinc concentrate. Minor amounts of gold (2867 kg) and silver (91,320 kg) were also produced. The value of the production totalled \$58,732,366.72.

Currently, all rights and leases have lapsed to the Crown.

STUDY METHODS AND MATERIALS

Study Design

Four sampling blocks were selected for the purposes of the study. Sherlett Lake (Figure 2) was selected both as an upstream control and because of Sherridon residents' concern regarding the integrity of their water supply. Camp Lake (Figure 3) was an obvious selection due to the proximity of the tailings. A three hectare area adjacent to the Camp Lake outfall (Block "A", Figure 3) was thought likely to be the most adversely impacted area of Cold Lake. The sixty hectare area adjacent to the community of Cold Lake (Block "B", Figure 3) was considered both as being representative of cumulatively impacted areas downstream of the potential tailings drainage path and because of residents' concerns regarding the integrity of their water supply.

A total of fifteen sampling stations per block were randomly identified. This was accomplished by superimposing a numbered grid upon diagrams of each sampling block and utilizing random numbers tables (Rand Corp., 1955) to determine grid reference points.

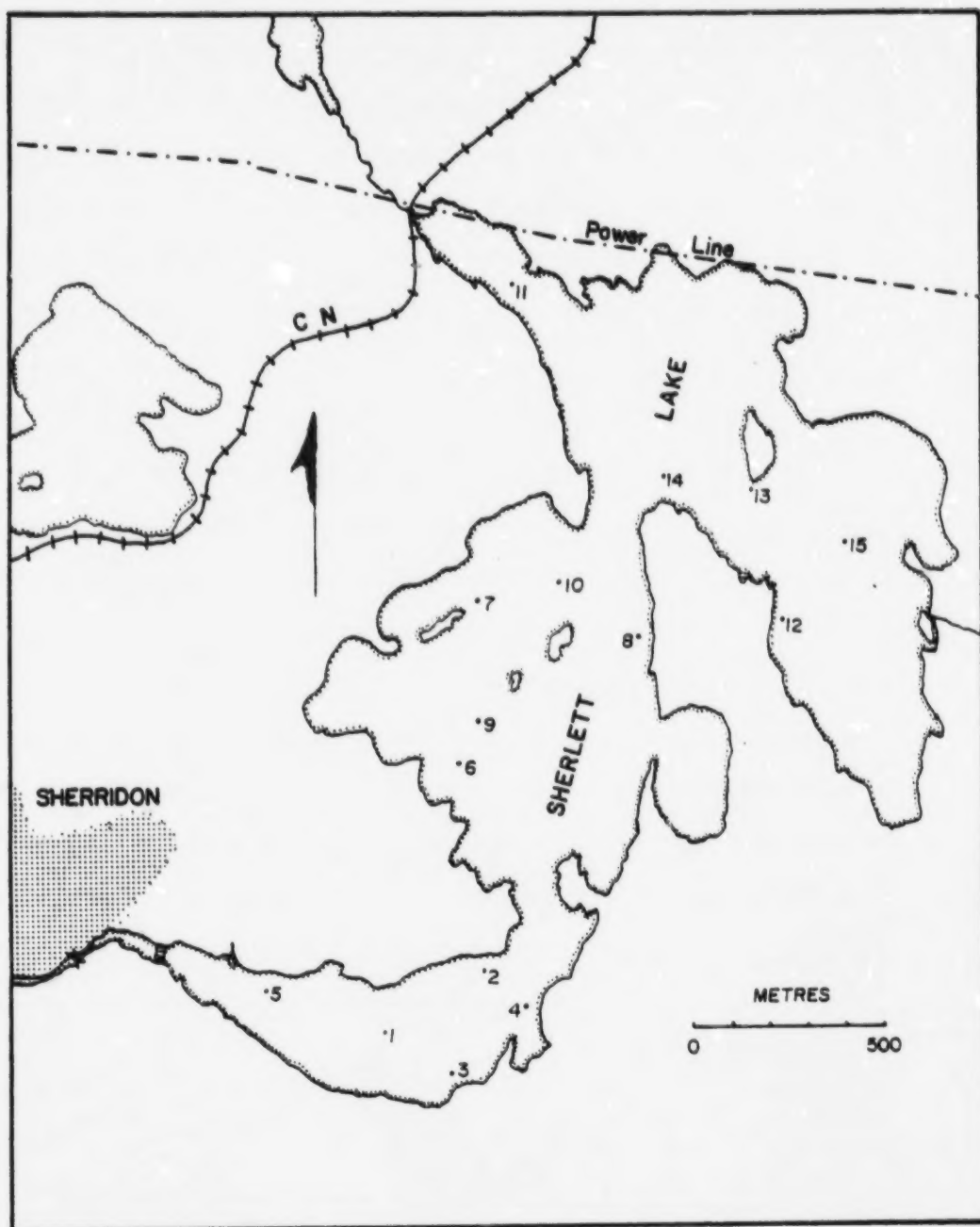


Figure 2: Sherlett Lake sampling stations

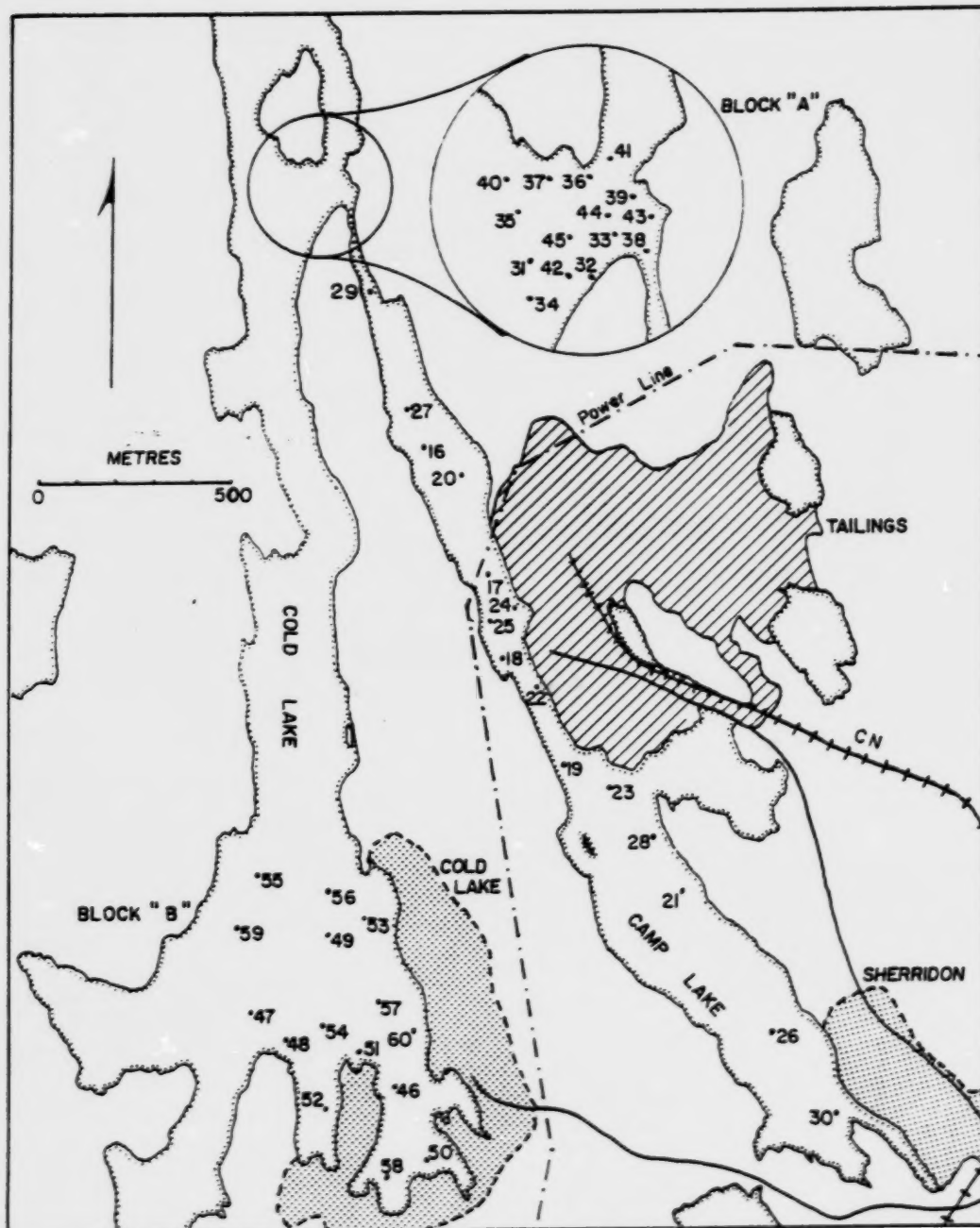


Figure 3: Sampling stations on Camp Lake and Blocks "A" and "B" of Cold Lake.

Field Procedures

Transportation to and from the study area was via charter air service from Flin Flon. Charter air service was also employed to transport perishable water samples to Flin Flon, whence the samples were freighted to Winnipeg via scheduled bus service. Technical Services Laboratory receipt of these samples was thus assured within forty-eight hours of collection. Transportation about the study area was by outboard motor boat rented from a local fishing lodge.

A four litre acrylic Kemmerer sampler was used to collect water at random depths from each of the randomly identified stations. Random depths were determined by considering random numbers (Rand Corp. 1955) as a percentage of the total depth of each station. Volumes collected were sufficient for laboratory analysis of the requested twenty-four physicochemical parameters*. Essential preservatives were added where required immediately following collection of each sample. Water temperatures were measured and recorded on site. Attempts to determine pH and conductivity values on site were unsuccessful due to instrument failure. All water samples were shipped as previously described in order to assure commencement of analysis within forty-eight hours of collection.

* Parameters listed in Table 1.

Sediments from each station were collected by using a 22.9 centimetre square Ekman dredge. Upon hoisting the Ekman grab sample to the lake surface, the top of the dredge was carefully opened so as to avoid disturbance of the delicate water-sediment interface. A five centimetre diameter clear acrylic tube was then inserted through the dredge contents. Excess water and sediments more than five centimetres below the interface were carefully drained from the tube. The remaining contents of the tube were then drained into a labelled "whirl-pak". All sediment samples were placed in a local freezer within six hours of collection and were maintained in a frozen state until submission to the Technical Services Laboratory.

Fish were primarily collected by overnight deployment of gangs of 95.3 and 105 mm mesh gill nets set at suitable locations within Sherlett and Cold Lakes. Gill nets were not set in Camp Lake because conditions did not appear suitable for fish life and severe damage to nets (by snagging on underwater projections and staining of mesh) was anticipated. Catches of pike and walleye from Cold Lake and Sherlett Lake were supplemented by angling. The total catch per block was identified to species and tallied. A maximum of twenty individuals per species per block, each representative of the size range of cisco, pike, common sucker, walleye, whitefish, burbot and perch collected, were then selected for sampling. Each individual was assigned an identification number, weighed to the nearest 10 grams, measured to the nearest 0.1 centimetre and sexed.

Evidences of age, consisting of either otoliths, cleithra or pelvic fin rays (species dependent), were removed at this time. Specimens were then filleted and lateral muscle tissue inserted into labelled "whirlpacs". All tissue samples were placed in a local freezer upon collection and were maintained in a frozen state until submission to the Technical Services Laboratory.

Shoreline rubble materials in the outlet areas of Sherlett, Camp and Cold Lakes were searched for crayfish and other invertebrates in order to garner information respecting metals bioaccumulation. Though crayfish were abundant at the Sherlett outlet, failure to collect or even observe crayfish and other invertebrate specimens at the Camp Lake outlet forced abandonment of this avenue of investigation.

The tailings disposal area was also inspected. Surface runoff patterns and runoff impoundment drainage routes were documented. Additionally, four subsurface (0.3 metres) samples of tailings were collected from various locations on the site (Figure 4). These were placed in a local freezer and maintained in a frozen state until submission to the Technical Services Laboratory.

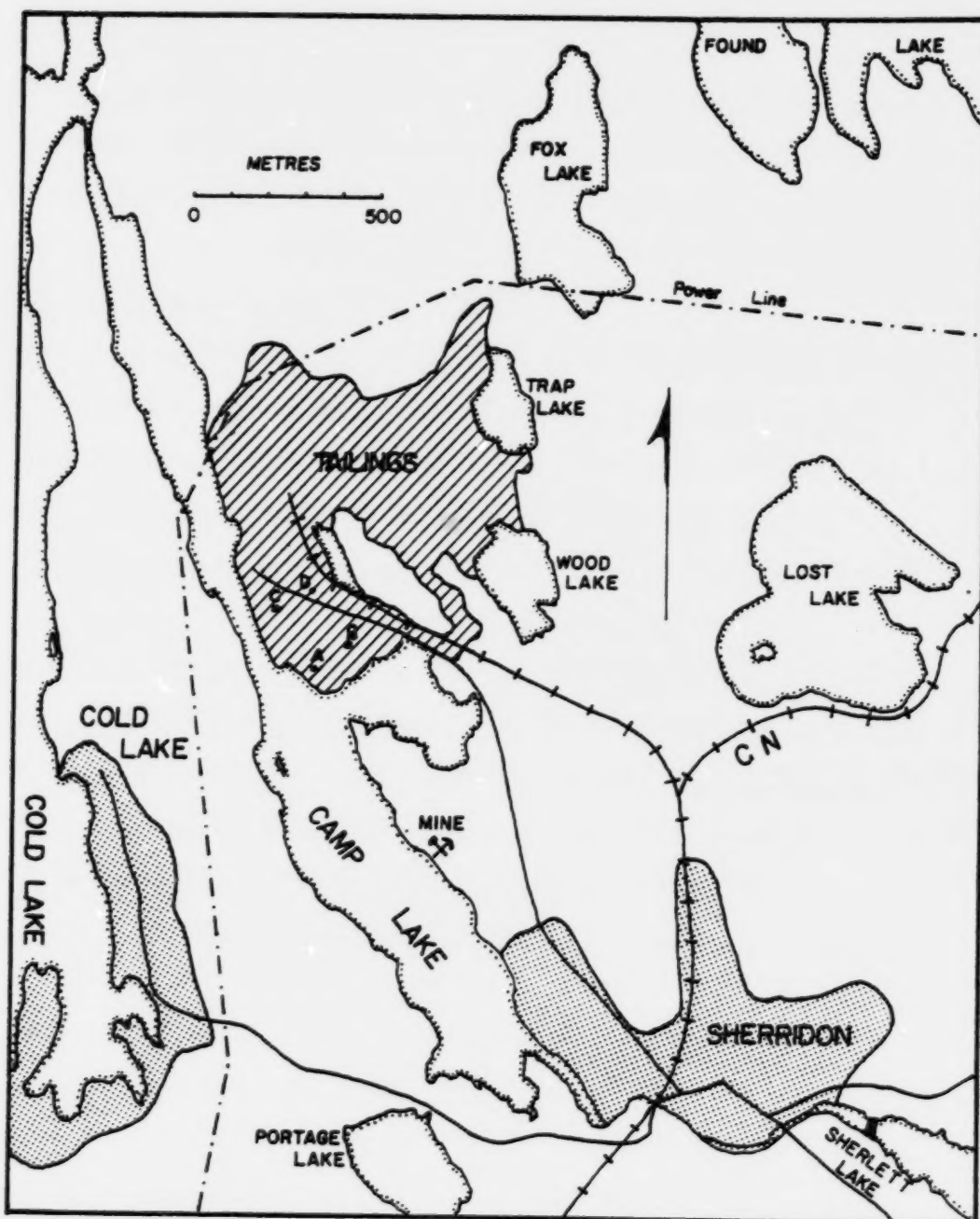


Figure 4: The tailings disposal area.

Analytical Procedures

Immediately upon receipt by Technical Services Laboratory water samples were refrigerated and frozen samples of tissue, sediments and tailings were stored in freezers. All samples were analyzed prior to shelf-life expiration according to methods described by Sorba et al (1980).

Fish evidences of age were submitted for age determination to the Biological Services Branch of the Manitoba Department of Natural Resources.

Upon completion of analyses, all data were tabulated and summarized. Analysis of variance (F0.95) was performed on water and sediment analytical results. Duncan's multiple range test ($\alpha=0.05$) was then applied to parameters showing significant differences. Regressions of certain Cold Lake Block "A" water physicochemical parameters and sediment metal concentrations on respective estimated direct water distance (m) from the Camp Lake outfall were developed and tested for significance ($\alpha =0.05$). Fish muscle tissue metal concentrations were compared to those of fish from Gods and Wekusko Lakes.

RESULTS AND DISCUSSION

Water Physicochemistry

Water physicochemical data are detailed in Appendix 1(a-d). Summarizations on an individual lake basis are presented in Tables 1-4, respectively. Analysis of variance and Duncan's multiple range comparisons are presented in Table 5.

(a) Sherlett Lake

Sherlett Lake appeared typical of medium depth shield lakes that border on oligotrophy. Thermal stratification was not observed as temperatures ranged from 11.0 to 17.0 °C. Stable thermoclines are unlikely to develop on Sherlett Lake due to the relatively shallow depth. Conductivities were low and the mean of 61.2 µS/cm was compatible with the precambrian nature of the watershed. Water clarity was also normal as both mean turbidity (0.88 mg/L) and non filterable residues (LS.0 mg/L) were low.

Physicochemical assessments of productivity and the potential for productivity were also typical of medium depth shield lakes bordering on oligotrophy. Mean dissolved oxygen concentrations and calculated degrees of saturation (9.6 mg/L and 95.3%, respectively) indicated that oxygen depletion was not occurring. The potential for productivity, as indicated by nutrient levels (concentrations of phosphorus and the nitrogens), was low and suggested no anthropogenic enrichment. Trophically, Sherlett Lake was considered oligo-mesotrophic (Vollenweider, 1968) and problems such as oxygen depletion and algal blooms were not expected.

TABLE 1: SUMMARIZATION OF WATER PHYSICOCHEMICAL DATA FROM SHERLETT LAKE

PARAMETERS		STATISTIC*	$\bar{x}$	δ	Hi	Lo
Field Temperature	(°C)		15.0	2.41	17.0	11.0
Conductivity	(μ S/cm)		61.2	1.77	64.1	58.7
Non Filt. Residue	(mg/L)		<5.0	0.0	<5.0	<5.0
pH	(logarithmic mean)		7.45	0.14	7.60	7.05
Total Alkalinity (CaCO ₃)	(mg/L)		23.1	0.59	24.0	22.0
Alkalinity (HCO ₃)	(mg/L)		28.2	0.73	29.3	26.8
Alkalinity (CO ₃)	(mg/L)		0.0	0.0	0.0	0.0
Alkalinity (OH)	(mg/L)		0.0	0.0	0.0	0.0
Dissolved Oxygen	(mg/L)		9.6	0.60	10.4	7.8
Total Organic Carbon	(mg/L)		16.2	0.56	17.0	15.5
Total Inorganic Carbon	(mg/L)		4.5	0.69	6.5	4.0
Turbidity	(NTU)		0.88	0.065	1.00	0.75
Total Kjeldhal Nitrogen	(mg/L)		0.40	0.0	0.40	0.40
Diss. Nitrate-Nitrite-Nitrogen	(mg/L)		<0.01	0.0	<0.01	<0.01
Total Phosphorus	(mg/L)		0.014	0.002	0.018	0.011
Free Cyanide	(mg/L)		<0.02	0.0	<0.02	<0.02
Extractable Arsenic	(mg/L)		<0.001	0.0	<0.001	<0.001
Extractable Cadmium	(mg/L)		<0.005	0.0	<0.005	<0.005
Extractable Copper	(mg/L)		0.022	0.021	0.070	<0.005
Extractable Lead	(mg/L)		<0.005	0.0	<0.005	<0.005
Extractable Nickel	(mg/L)		<0.005	0.0	<0.005	<0.005
Extractable Zinc	(mg/L)		0.01	0.008	0.04	<0.01
Extractable Calcium	(mg/L)		7.03	0.091	7.31	6.97
Extractable Magnesium	(mg/L)		2.20	0.023	2.23	2.16
Extractable Mercury	(μ g/l)		<0.02	0.0	<0.02	<0.02

* Note: $\bar{x}$ = mean
 δ = standard deviation
Hi = largest value
Lo = smallest value

Buffering capacities are popularly of concern with respect to acid precipitation, and were of concern to the present study because the sulphide nature of the ore processed at the Sherridon mill suggested a high acid generation potential. The present study's usage of Sherlett Lake as a control or background reference point, thus considered definition of pH and corresponding buffering capacity a major objective. Sherlett Lake pH and buffering capacity proved no exception to those of lakes located within "hard" precambrian shield watersheds. Buffering capacity, as indicated by alkalinities and calcium and magnesium ion concentrations, was low but still within the range typical of the watershed type (Water Standards and Studies Section, unpublished data). Minimal buffering capacity was present. The mean pH (logarithmic mean 7.45) was also within the range common to lakes located in such "hard" precambrian shield areas as the Bisset-north locale and the Flin Flon area (IBID). Thus, a normal pH coupled with minimal buffering capability were indicative of no detectable anthropogenic impact upon Sherlett Lake.

High acid generation potential is frequently linked to metal contamination of the water column. Thus examination of metal concentrations in the Sherlett Lake water column was also a primary objective of the present study. Potentially troublesome metals such as arsenic, cadmium, lead, nickel and mercury were not detected in any of the water samples. Zinc and copper were detected in 20% and 87%, respectively, of the Sherlett Lake water samples. The highest values and mean values for each (Cu, 0.070 and 0.022 mg/L; Zn, 0.04 and 0.01 mg/L, respectively) were, however, well within the

range considered normal for shield lakes. Both mean copper and zinc concentrations compared favourably to their counterparts from such lakes as Gods (Beck, 1982), Snow (Beck, in prep.) and Wekusko (Brown et al, 1980).

Although cyanide was not known to have been used in the metal recovery process at the Sherridon mill, standard precautionary procedures dictated its analysis during the present study. Free cyanide was not detected in any water samples.

Two factors, namely potability as a supply source for the community of Sherridon and suitability as a study control, were of interest respecting summation of Sherlett Lake water quality. Regarding potability, the physicochemical parameters examined did not show cause for concern nor did they suggest anthropogenic impacts. Water column metal concentrations, a subject which had aroused concerns among Sherridon residents, were all well below the respective recommended objective concentrations described in the Guidelines for Drinking Water Quality (1978)*.

* Limits for certain physicochemical parameters as recommended by the Guidelines for Drinking Water Quality (1978):

<u>Parameter</u>		<u>Maximum Acceptable Concentration</u>	<u>Objective</u>	<u>Reason</u>
pH	(units)	6.5 - 8.5	-	Aesthetics
Turbidity	(NTU)	5	1	Aesthetics
As	(mg/L)	0.05	≤0.005	Health
Cd	(mg/L)	0.005	≤0.001	Health
Pb	(mg/L)	0.05	≤0.001	Health
Hg	(ug/l)	0.1	≤0.02	Health
NO ₃ & NO ₂	(mg/L)	10.0	≤0.001	Health
CN	(mg/L)	0.2	≤0.002	Health
Cu	(mg/L)	1.0	<1.0	Aesthetics
Fe	(mg/L)	0.3	≤0.05	Aesthetics
Mn	(mg/L)	0.05	<0.01	Aesthetics
Zn	(mg/L)	5.0	<5.0	Aesthetics

Sherlett Lake was also shown to be eminently suitable as a control for the present study. The lake is physically located within the same watershed as the impacted area and its physicochemical characteristics were both typical of the watershed type and showed no detectable anthropogenic impacts.

(b) Camp Lake

Camp Lake appeared atypical of medium depth shield lakes in virtually all respects except temperature. Lake temperatures averaged 15.4°C and were comparable to other lakes of the study area. However, a thermocline had developed at the 6.0 m level and temperatures of 4.7°C were observed in the hypolimnion. The thermocline was thought to be stable due to the protective hills surrounding Camp Lake and because the long axis of the lake was oriented perpendicular to prevailing winds. The mean conductivity ($154.8 \mu\text{S}/\text{cm}$) was at least 50% greater than might be expected in a medium depth "hard" shield lake. The greatest value ($599 \mu\text{S}/\text{cm}$) in particular indicated an abnormal abundance of ions in the water column. Water clarity also suggested anthropogenic impactation as both mean turbidity (9.67 NTU) and mean non filterable residue ($11.1 \text{ mg}/\text{L}$) were greater than anticipated for a shield lake that was well protected from strong winds. Field observations noted that much of the direct impairment of clarity was apparently due to suspended particulate matter which closely resembled rust and to a surface scum somewhat similar to a trace oil slick. (An oil spill was not implicated as the characteristic multihue colour was not observed).

TABLE 2: SUMMARIZATION OF WATER PHYSICOCHEMICAL DATA FROM CAMP LAKE

PARAMETERS	STATISTIC*	$\bar{x}$	δ	Hi	Lo
Field Temperature	(°C)	15.4	3.44	18.0	4.7
Conductivity	(μ S/cm)	154.8	54.16	599.0	104.0
Non Filt. Residue	(mg/L)	11.1	5.91	24.0	<5.0
pH	(logarithmic mean)	4.21	0.74	6.30	3.20
Total Alkalinity (CaCO ₃)	(mg/L)	0.8	1.78	6.00	0.0
Alkalinity (HCO ₃)	(mg/L)	1.0	2.17	7.32	0.0
Alkalinity (CO ₃)	(mg/L)	0.0	0.0	0.0	0.0
Alkalinity (OH)	(mg/L)	0.0	0.0	0.0	0.0
Dissolved Oxygen	(mg/L)	8.05	0.69	10.2	7.5
Total Organic Carbon	(mg/L)	8.5	1.54	11.5	6.0
Total Inorganic Carbon	(mg/L)	1.1	0.30	2.0	<1.0
Turbidity	(NTU)	9.67	7.13	35.0	5.5
Total Kjeldhal Nitrogen	(mg/L)	0.29	0.14	0.70	0.20
Diss. Nitrate-Nitrite-Nitrogen	(mg/L)	<0.01	0.0	0.01	<0.01
Total Phosphorus	(mg/L)	0.006	0.0024	0.012	0.003
Free Cyanide	(mg/L)	<0.02	0.0	<0.02	<0.02
Extractable Arsenic	(mg/L)	<0.001	0.0	<0.001	<0.001
Extractable Cadmium	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Copper	(mg/L)	0.07	0.03	0.16	0.04
Extractable Lead	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Nickel	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Zinc	(mg/L)	0.34	0.13	0.76	0.20
Extractable Calcium	(mg/L)	10.69	1.74	16.8	9.38
Extractable Magnesium	(mg/L)	4.43	1.22	8.70	3.51
Extractable Mercury	(ug/l)	<0.02	0.0	<0.02	<0.02

* Note: $\bar{x}$ = mean
 δ = standard deviation
Hi = largest value
Lo = smallest value

Field observations suggested very limited submergent aquatic life. Macroscopic plants and animals were not observed below the water surface of Camp Lake. The sole surface organisms observed included numerous water striders (*Gerridae*) and, infrequently, several loons. The sole emergent vegetation observed consisted of an unidentified sedge (*Carex* sp) located infrequently about the shoreline and several water arum (*Calla palustris*) beds located near the outlet. Physicochemical results tended to confirm the field observations. Although the mean dissolved oxygen concentration (8.05 mg/l) was relatively high, the mean level of saturation was only 80%. This suggested that photosynthesis and direct atmospheric dissolution were unable to fully compensate for biological and/or chemical oxygen demand. The results were also suggestive of impaired photosynthesis and the potential development of anoxic conditions during winter ice cover. Mean total organic carbons (8.5 mg/l) were relatively low for the lake type and were thus indicative of poor productivity.

Buffering capacity and pH were perhaps the most outstanding features of Camp Lake physicochemistry. Water Standards and Studies Section has not detected concentrations of total and bicarbonate alkalinities (means, 0.8 and 1.0 mg/l, respectively) as low in any other Manitoba lake yet sampled. Clearly the buffering capabilities present in the water column have been almost entirely utilized to counterbalance acid generation. That the buffering capacity was inadequate to neutralize acids generated was evident from the low mean pH (4.21) encountered. The lowest pH values observed in Camp Lake (3.20) are reportedly toxic to fish and many other aquatic

life forms. Only high specialized flora and fauna are able to survive successfully in this type of environment (McKee and Wolf, 1963; Rahel and Magnusson, 1983). The source of the acid generated appeared to be the tailings disposal area which abuts Camp Lake. Sulphides present in the tailings are readily converted to sulphuric acid upon chemical interaction with water and oxygen. The process occurs both directly in the lake from tailings materials transported by runoff and, with rainfall, directly on the tailings disposal area itself.

Considering the low pH encountered, it was surprising that arsenic, cadmium, lead, mercury and nickel were not detected in any water samples from Camp Lake. Apparently these particular metals did not constitute a significant component of either the ore body or the tailings materials. Copper and zinc, however, were detected in all samples. The mean copper concentration encountered (0.07 mg/L) would pose no problem for fish and other organisms under normal hardwater conditions (McKee and Wolf, 1963; Spear and Pierce, 1979), but would inhibit growth of algae and sensitive macrophytes (Spear and Pierce, 1979). However, concentrations as low as 0.015 mg/L copper have been reported toxic to most aquatic fauna and flora under soft water-low pH conditions such as occur in Camp Lake (op cit). Additionally, zinc in the concentrations observed (mean, 0.34 mg/L), has been reported toxic to many aquatic life forms due to synergism with copper (IBID; Spear, 1981). The absence of macroscopic organisms observed and the paucity of macroscopic flora present within the water column of Camp Lake thus appeared due to

the toxicity of copper and zinc synergism compounded by soft water-low pH conditions. Because copper and zinc concentrations were well above background levels (i.e. Sherlett Lake concentrations), it was evident that acidic waters draining the tailings area were dissolving these metals from the tailings and transporting them to Camp Lake.

Free cyanide was not detected in any water samples from Camp Lake.

Camp Lake water quality has been seriously degraded to the point where macroscopic life forms native to the study area appeared to be absent from the water column. The combination of low pH and high concentrations of copper and zinc provided an environment toxic to fish and other organisms. The source of degradation appeared to be the leachate and particulate materials drained from the adjacent tailings disposal area. These factors were of significance because of the potential impact of Camp Lake drainage to Cold Lake.

(c) Cold Lake Block "A"

Block "A" constituted the initial receiving water for Camp Lake effluent. Thus notable impacts of a chemical nature were anticipated for some parameters on the basis of proximity to the mouth of the Camp Lake outfall. Purely physical features such as temperature were not expected to be impacted.

TABLE 3: SUMMARIZATION OF WATER PHYSICOCHEMICAL DATA FROM COLD LAKE
BLOCK "A"

PARAMETERS		STATISTIC*			
		$\bar{x}$	δ	Hi	Lo
Field Temperature	(°C)	15.3	0.58	16.1	14.2
Conductivity	(μ S/cm)	126.0	22.8	172.0	108.0
Non Filt. Residue	(mg/L)	7.0	1.8	11.0	<5.0
pH	(logarithmic mean)	6.20	1.02	6.55	4.10
Total Alkalinity (CaCO ₃)	(mg/L)	4.07	3.20	9.00	0.0
Alkalinity (HCO ₃)	(mg/L)	4.96	3.90	11.00	0.0
Alkalinity (CO ₃)	(mg/L)	0.0	0.0	0.0	0.0
Alkalinity (OH)	(mg/L)	0.0	0.0	0.0	0.0
Dissolved Oxygen	(mg/L)	9.8	0.50	10.5	8.9
Total Organic Carbon	(mg/L)	8.8	0.68	9.5	7.0
Total Inorganic Carbon	(mg/L)	1.2	0.32	2.0	<1.0
Turbidity	(NTU)	3.20	1.25	5.0	2.0
Total Kjeldhal Nitrogen	(mg/L)	0.22	0.037	0.30	0.20
Diss. Nitrate-Nitrite-Nitrogen	(mg/L)	0.01	0.0005	0.02	0.01
Total Phosphorus	(mg/L)	0.006	0.00016	0.010	0.004
Free Cyanide	(mg/L)	<0.02	0.0	<0.02	<0.02
Extractable Arsenic	(mg/L)	<0.001	0.0	<0.001	<0.001
Extractable Cadmium	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Copper	(mg/L)	0.050	0.045	0.200	0.020
Extractable Lead	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Nickel	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Zinc	(mg/L)	0.22	0.063	0.34	0.17
Extractable Calcium	(mg/L)	9.44	0.0433	10.3	8.96
Extractable Magnesium	(mg/L)	3.73	0.247	4.27	3.49
Extractable Mercury	(ug/l)	<0.02	0.0	<0.02	<0.02

* Note: $\bar{x}$ = mean
 δ = standard deviation
Hi = largest value
Lo = smallest value

Conductivities averaged at least 25% greater (mean 126.0 $\mu\text{S/cm}$) than unimpacted lakes in a similar geophysical setting (Water Standards and Studies Section, unpublished data). The abnormal conductivity was directly attributed to ion loading by the Camp Lake effluent. A significant ($\alpha=0.05$) correlation ($r^2=0.69$) was observed for the linear relationship [$\mu\text{S/cm} = 163.3 + \text{metres} (-0.89)$] which described conductivities increasing in a linear fashion as the effluent mouth was approached. Field observations suggested that water clarity followed a similar pattern as a trail of foam originating from the effluent mouth extended 30 to 50 metres into Block "A" during low wind periods. However, correlations of both turbidity and non filterable residue values to effluent mouth proximity were not significant.

Nutrient concentrations were not expected to be elevated as Camp Lake had not received anthropogenic enrichment. Nutrient concentrations were therefore viewed solely as being indicative of trophic status. Both mean phosphorus (0.006 mg/L) and the nitrogen levels (total Kjeldhal nitrogen 0.22 mg/L; $\text{NO}_3\text{-NO}_2$, 0.01 mg/L) were low and suggested an oligotrophic status (Vollenweider, 1968). Dissolved oxygen levels were consistent with this classification as saturation levels averaged 102%.

Buffering capacity and pH appeared to be significantly impacted by Camp Lake discharges. Both total and bicarbonate alkalinities (means: 4.07 mg/L, 4.96 mg/L; respectively) were somewhat lower than might be expected for lakes situated in "hard" precambrian locales. Additionally, linear relationships describing

the concentrations of each as decreasing with proximity to the Camp Lake outfall [$\text{mg/L CaCO}_3 = 0.62 + \text{metres } (-0.80)$; and $\text{mg/L HCO}_3 = 0.61 + \text{metres } (-0.98)$; respectively] were significantly correlated ($r^2 = 0.62$, and 0.61 , respectively). The mean pH (6.20) was also lower than might be expected for an unimpacted lake of the area. Like the alkalinities, a significantly correlated ($r^2 = 0.72$) regression described pH as decreasing linearly with proximity to the mouth of the Camp Lake outfall [$\text{pH} = 3.94 + \text{metres } (0.04)$].

Concentrations of arsenic, cadmium, lead, mercury and nickel were below the detection limits in each of the water samples. Clearly these metals pose no environmental concern in the water column of the area. Mean copper concentrations (0.050 mg/L) were considered slightly above normal but still within the range common to lakes located in a similar geophysical setting. A significant correlation between water column copper concentrations and proximity to the mouth of the Camp Lake outfall was not observed ($r^2 = 0.23$). However, mean zinc concentrations (0.22 mg/L) were substantially greater than considered normal for the area. Additionally, the linear regression [$\text{mg/L Zn} = 0.32 + \text{metres } (-0.0025)$] which described zinc concentrations as increasing with proximity to the mouth of the Camp Lake outfall, was significantly correlated ($r^2 = 0.70$). Thus it was evident that elevated water column zinc concentrations were directly attributable to loadings from Camp Lake effluent.

Free cyanide was not detected in any of the water samples.

The water quality of Block "A" has been degraded considerably. Reduced alkalinities and pH and elevated conductivities and zinc concentrations were all directly attributed to loadings from Camp Lake effluent. The impact of these degraded conditions upon biota native to the study area was rather difficult to assess. Literature describing tolerances and/or toxicities pertaining to zinc and copper under varying pH and alkalinity conditions leave a nebulous region about the sort of conditions occurring with Block "A" waters. Generally it appeared that Block "A" waters would not prove acutely lethal to fish and most other aquatic life forms as most organisms would demonstrate simple avoidance behaviour. Sensitive forms of low motility, however, likely would not survive the adverse conditions near the Camp Lake outfall.

(d) Cold Lake Block "B"

Block "B" was located approximately 2.0 kilometres downstream of Block "A". Therefore Block "A" parameters notably affected by Camp Lake effluent had considerable opportunity for dilution before arriving at the Block "B" area. Conductivities for example, were generally at the upper limits of the range found within "hard" precambrian shield areas. However, when the mean (104.4 $\mu\text{S}/\text{cm}$) was compared to that of Sherlett Lake (61.2 $\mu\text{S}/\text{cm}$), degradation by Camp Lake effluent was implicated. Water clarity did not exhibit any indication of degradation as both non filterable residue and turbidity means (<5.0 mg/L and 1.43 NTU; respectively) were low.

TABLE 4: SUMMARIZATION OF WATER PHYSICOCHEMICAL DATA FROM COLD LAKE
BLOCK "B"

PARAMETERS		STATISTIC*			
		$\bar{x}$	δ	Hi	Lo
Field Temperature	(°C)	14.7	1.92	16.0	10.0
Conductivity	(μ S/cm)	104.4	2.05	107.0	99.6
Non Filt. Residue	(mg/L)	<5.0	0.0	<5.0	<5.0
pH	(logarithmic mean)	6.97	0.10	7.10	6.75
Total Alkalinity (CaCO ₃)	(mg/L)	10.50	1.61	14.0	9.0
Alkalinity (HCO ₃)	(mg/L)	12.81	1.96	17.1	11.0
Alkalinity (CO ₃)	(mg/L)	0.0	0.0	0.0	0.0
Alkalinity (OH)	(mg/L)	0.0	0.0	0.0	0.0
Dissolved Oxygen	(mg/L)	9.5	1.86	10.2	2.8
Total Organic Carbon	(mg/L)	9.8	0.45	10.5	9.0
Total Inorganic Carbon	(mg/L)	1.3	0.56	3.0	1.0
Turbidity	(NTU)	1.43	0.18	1.5	0.95
Total Kjeldhal Nitrogen	(mg/L)	0.33	0.04	0.4	0.3
Diss. Nitrate-Nitrite-Nitrogen	(mg/L)	0.012	0.006	0.03	<0.01
Total Phosphorus	(mg/L)	0.009	0.001	0.011	0.007
Free Cyanide	(mg/L)	<0.02	0.0	<0.02	<0.02
Extractable Arsenic	(mg/L)	<0.001	0.0	<0.001	<0.001
Extractable Cadmium	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Copper	(mg/L)	0.05	0.044	0.19	0.02
Extractable Lead	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Nickel	(mg/L)	<0.005	0.0	<0.005	<0.005
Extractable Zinc	(mg/L)	0.13	0.02	0.17	0.10
Extractable Calcium	(mg/L)	8.76	0.28	9.60	8.34
Extractable Magnesium	(mg/L)	3.38	0.11	3.70	3.20
Extractable Mercury	(ug/l)	<0.02	0.0	<0.02	<0.02

* Note: $\bar{x}$ = mean
 δ = standard deviation
Hi = largest value
Lo = smallest value

Physicochemical assessments of productivity and the potential for productivity were indicative of unimpacted conditions. Mean dissolved oxygen concentrations (9.5 mg/L) and saturation levels (94%) suggested that photosynthesis was not impaired and was able to compensate for biological and chemical oxygen demands within the water column. The single instance of oxygen depletion (2.8 mg/L) observed involved a sample (station #55) collected at 93% of the total depth. Bottom layers of water from many lakes frequently suffer oxygen depletion and the occurrence at Cold Lake was not considered evidence of degradation. Nutrient levels were compatible with the geophysical setting and did not suggest anthropogenic enrichment. Trophically, the site was considered oligotrophic (Vollenweider, 1968).

Buffering capacity appeared somewhat impacted by Camp Lake discharges. Mean total and bicarbonate alkalinities (10.50 mg/L, and 12.81 mg/L, respectively) were lower than might be expected for an unimpacted lake of the area. Mean pH (6.97) was not affected as severely as buffering capacity. Although the mean value suggests some degree of impact, the mean pH is still within the range common to lakes situated in a similar geophysical setting. Evidently, sufficient buffering capability existed with Block "B" waters to partially compensate for the present acidic influxes.

Block "B" waters, like others of the study area, did not contain detectable concentrations of extractable arsenic, cadmium, lead, mercury or nickel. Mean copper concentrations (0.05 mg/L) were low, but the presence of detectable levels at all sampling

stations may be indicative of loadings from Camp Lake discharges. However, as the range and mean of Block "B" copper values closely approximated those of Block "A", it was also possible that the levels encountered were characteristic of the entire Kississing Lake. Unlike copper, and as in Block "A", Block "B" zinc concentrations appeared somewhat elevated beyond normal values. Mean zinc concentrations (0.13 mg/L) were one order of magnitude greater than Sherlett (0.01 mg/L) and exceeded the range common to unimpacted lakes situated in similar geophysical settings.

Free cyanide was not detected in any Block "B" water samples.

Potability as a supply source for the community of Cold Lake and quality of habitat for aquatic organisms were the two primary factors of interest respecting summation of Block "B" water quality. Regarding potability, all metals examined including copper and zinc occurred at levels well below the respective objective concentrations recommended by the Federal-Provincial Working Group on Drinking Water (1978). All other physicochemical parameters examined for which drinking water recommendations (Ibid) exist, were also well below either objective or maximum acceptable concentrations. Thus it was clear that Block "B" constituted an acceptable source for potable watersupply. Regarding quality of habitat, levels of various parameters as discussed by McKee and Wolfe (1963) Spear (1981) and Spear and Pierce (1979) suggest that Block "B"

waters would not pose a hazard to aquatic organisms native to the study area. However, avoidance behaviour by highly motile forms such as fish may occur.

(e) Synopsis

Having discussed the status of each of the study sites individually, a holistic approach is now utilized in order to better illustrate the total impact of the Sherridon mine site upon water quality within the study area. Block mean values for several significantly impacted physicochemical parameters (Table 5) were illustrated (Figure 5) in order to facilitate this overview. Additionally, the rank statistic described in Table 5 readily indicates which parameters are impacted⁽¹⁾ and the relative significant differences between sampling blocks⁽²⁾.

-
- (1) Table 5 notation of the order C-A-B-S suggests loading from Camp Lake whereas the order S-B-A-C suggests inhibition or dilution due to Camp Lake discharges.
- (2) The symbols for sampling blocks with statistically similar levels of a particular parameter are underscored.

TABLE 5: Comparisons and Rank of Sherridon Area Lakes Water Physicochemistry

PARAMETERS	STATISTIC	SIGNIFICANT DIFFERENCES PER ANALYSIS OF VARIANCE		RANK AND SIMILARITY PER DUNCAN'S MULTIPLE RANGE TEST ($\alpha=0.05$) (*)
		F	F0.95	
Conductivity		12.7	3.40	C <u>A</u> B S
Non Filt. Residue		13.1	3.39	C <u>A</u> B S
pH		111.2	3.40	<u>S</u> B A C
Total Alkalinity (CaCO_3)		246.5	3.39	S B A C
Alkalinity (HCO_3)		246.9	3.39	S B A C
Alkalinity (CO_3)		0	3.39	IDENTICAL
Alkalinity (OH)		0	3.39	IDENTICAL
Dissolved Oxygen (% Saturation)		6.7	3.40	<u>A</u> S B C
Total Organic Carbon		236.4	3.39	S B <u>A</u> C
Total Inorganic Carbon		18.3	3.39	S <u>B</u> A C
Turbidity		18.7	3.39	C <u>A</u> B S
Total Kjeldhal Nitrogen		15.5	3.39	S <u>B</u> C A
Diss. Nitrate-Nitrite-Nitrogen		2.16	3.39	<u>A</u> B C S
Total Phosphorus		61.2	3.39	S B <u>A</u> C
Free Cyanide		0	3.39	IDENTICAL
Extractable Arsenic		0	3.39	IDENTICAL
Extractable Cadmium		0	3.39	IDENTICAL
Extractable Copper		5.09	3.39	C <u>A</u> B S
Extractable Lead		0	3.39	IDENTICAL
Extractable Nickel		0	3.39	IDENTICAL
Extractable Zinc		50.2	3.39	C A B S
Extractable Calcium		42.0	3.39	C <u>A</u> B S
Extractable Magnesium		33.5	3.39	C <u>A</u> B S
Extractable Mercury		0	3.39	IDENTICAL

(*) Lakes are ranked from highest to lowest value where
 S = Sherlett, C = Camp, A = Block "A" of Cold Lake
 and B = Block "B" of Cold Lake.
 Statistically similar lakes are underscored.

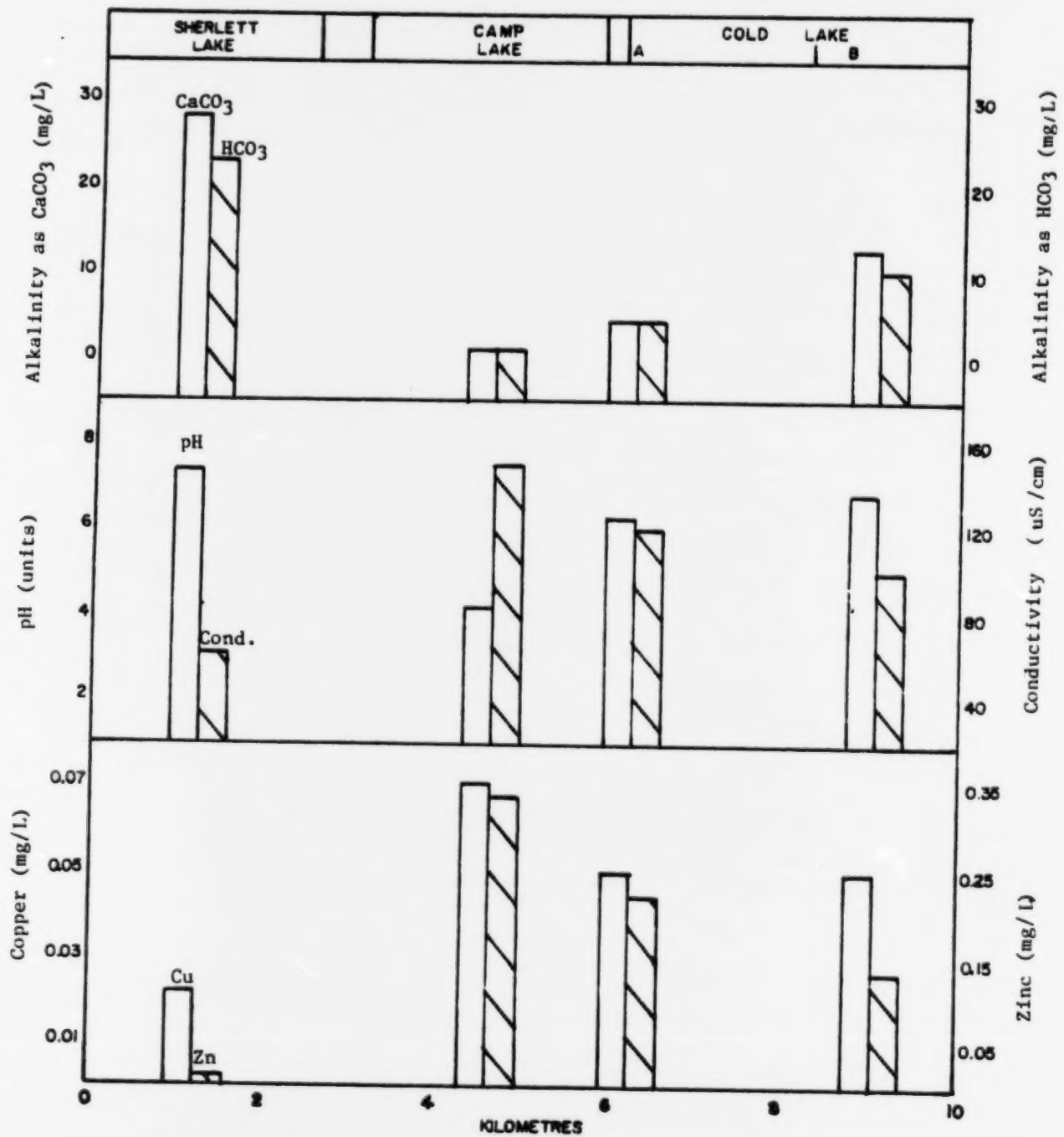


FIGURE 5: Mean Values of Some Significantly Impacted Water Physicochemical Parameters in Relation to Distances Within the Sherridon Study Area.

Many of the parameters examined evidenced no impact by drainage from the Sherridon mine and tailings site. Arsenic, cadmium, cyanide, lead, mercury and nickel levels were below detection limits at all sampling stations. Dissolved nitrate-nitrite forms of nitrogen from each sampling block were not significantly different at a 95% level of confidence and the rank suggested no impact due to Camp Lake discharges. Carbonate (CO_3) and hydroxyl (OH) forms of alkalinity, normally indicative of direct alkaline loadings such as caustic soda discharges, were naturally not detected at any station. Statistical similarity between the Camp Lake-Cold Lake Block "B" total nitrogen levels appeared to be a natural artifact as the order of rank did not suggest impact due to Camp Lake discharges.

The rank order for several parameters suggested that drainage from the tailings site had significantly impacted Camp Lake but Camp Lake discharges had not yet significantly affected downstream waters. Dissolved oxygen saturation levels appeared inhibited within Camp Lake but Cold Lake levels were indistinguishable from those of Sherlett. The rank order implied no effect upon Cold Lake waters. Non filterable residues, turbidity and extractable copper levels in Camp Lake were significantly elevated above the surrounding areas surveyed. Levels in downstream waters were not significantly different from Sherlett Lake, the control. However, the order of rank for the latter lakes suggested that the loadings of these parameters were impacting to a subtle

degree. Furthermore, it implied that continued discharges from Camp Lake would eventually result in significantly impacted nonfilterable residues, turbidity levels and extractable copper in downstream waters.

The rank order for several other parameters suggested that drainage from the tailings site was significantly inhibitive upon levels in Camp Lake and that Camp Lake discharges were having a similar significant impact upon downstream receiving waters. The pH and corresponding calcium carbonate (CaCO_3) and bicarbonate (HCO_3) alkalinities fell into this category. The alkalinities in particular appeared significantly impacted as mean values for each of the sampling blocks were significantly different at a 95% level of confidence. The pH appeared affected to a lesser degree as Block "B" waters had recovered sufficiently so as to exhibit no significant difference from control (Sherlett Lake) waters. Phosphorus and the total organic and inorganic carbons also fell into this grouping. Although suggestive of primary productivity inhibition, the interrelationships between phosphorus (a nutrient) and total organic carbon (a product of biological activity) are such that a clearly defined cause-effect statement could not be ascribed in this instance.

Four parameters evidenced significant impacts of an escalatory nature due to drainage from the tailings site. Zinc levels alone were directly attributable to loadings via tailings drainage and subsequent Camp Lake discharges. Elevated levels of

calcium and magnesium in receiving waters were indicative of bedrock leaching activity probably due to increased acidity (decreased pH) rather than direct loadings. The rank order of conductivity levels confirmed the deleterious nature of the levels of ion activity mentioned to in the preceding commentary.

Figure 5 illustrates the impact zone downstream of the Camp Lake discharge. Excluding copper, the degree of slope for each of the Block "A"- "B" relationships illustrated appeared remarkably similar. Extrapolation of these slopes suggested recovery to background (Sherlett Lake) levels occurred at approximately 6 to 8 kilometres from Block "A". This implied that although the degree of environmental degradation would not be detectable at a statistically significant level over the entire affected area, Camp Lake discharges were impacting upon Kississing Lake at a distance up to 8 kilometres downstream of the Cold Lake community. It also implied that the discharge, if continued, would progressively impact upon an ever expanding area.

Sediments and Tailings

The results of sediment and tailings analyses are detailed in Appendix 2(a-e). Summaries on an individual site basis are presented in Table 6. Table 7 describes significant differences between lakes, and ranks them on the basis of mean metal concentrations.

(a) Characteristics

Several physical features readily enabled distinction between sediments of various sampling blocks even prior to metals analysis. These features included colour, texture, degree of compaction and relative homogeneity.

Sediments from Sherlett Lake were typical of medium depth shield lakes. These consisted of medium compacted grey coloured silt-like materials. Samples from fourteen stations were of this nature and one sample (station 3) consisted of sand.

Camp Lake sediments were remarkably different from the above. These were composed of ochre coloured particles resembling flakes of rust. Compaction was virtually non existent as the uppermost approximately 10 centimeters were in a state of near suspension. All Camp Lake sediment samples were of this nature.

Sediments from Block "A" were unique because of the heterogeneity among samples. These ranged from rock, sand, organic debris and black silt to materials resembling Camp Lake sediments. One prominent common feature in most samples was a fine rust like layer overlying the substrate.

Apart from two stations where rock bottoms were encountered (stations 48 and 50), all Block "B" samples consisted of medium compacted black coloured silt-like materials.

Typically, tailings samples were ochre hued, well compacted and gritty in texture.

(b) Metals

Mean metal concentrations in Sherlett Lake sediments (Table 6) were considered to be background values normal for the study area. Thus significant differences from mean Sherlett Lake concentrations (Table 7) were considered indicative of impact from tailings drainage. Like water column results, sediment data also suggested varying degrees of impact. These varied from significant metal loadings to little detectable impact. Additionally, sediment metal concentrations appeared strongly influenced by water column pH levels.

Because the site had been abandoned for more than thirty years, it was conceivable that the surface of the tailings had achieved a level of near stasis as regards the more dilute metals. Dilute materials readily leachable from the tailings surface had likely already been transported to Camp Lake and had already been dispersed. This was similar to situations observed at Gods Lake (Beck, 1982) and at Snow Lake (Beck, in prep.). Significant correlations of sediment metal concentrations on proximity to the mouth of Camp Lake's outfall should have been observed for Block "A". Such was not the case as correlations for all metals were not significant at $\alpha = 0.05$.

TABLE 6: Summarization of Sediment and Tailings Analyses (*)

SITE	METAL STATISTIC**	WET Hg (μ/g)	DRY Hg (μ/g)	As (μ/g)	Cd (μ/g)	Cu (μ/g)	Pb (μ/g)	Ni (μ/g)	Zn (μ/g)	Fe (%)	Mn (μ/g)	CN (μ/g)
TAILINGS (N=4)	$\bar{x}$	2.22	2.81	98.25	2.3	1450	205	19	1337.5	27.0	92	<1.0
	δ	1.54	2.20	13.05	0.50	1108.6	33.17	4.0	495.61	5.16	22.7	0
	Hi	4.35	5.96	110.0	3	3000	240	25	1700	33.0	120	<1.0
	Lo	0.95	1.19	85.6	2	620	160	17	650	21.0	69	<1.0
CAMP LAKE (N=15)	$\bar{x}$	0.10	1.14	10.22	11.1	1223	32	25	3640	36.4	171	-
	δ	0.07	0.69	6.17	12.02	1534.7	13.7	7.56	5457	5.15	200.98	-
	Hi	0.27	2.42	28.80	39	6000	60	38	18,000	43.0	880	-
	Lo	<0.02	0.42	4.43	2	160	20	17	350	27.0	66	-
BLOCK "A" (N=14)	$\bar{x}$	0.10	0.37	7.09	5.2	595	26	32	1542	10.8	230	-
	δ	0.08	0.40	2.90	4.25	444.3	9.29	9.93	997.8	9.35	107.6	-
	Hi	0.26	1.46	11.20	15	1600	40	54	3400	42.0	420	-
	Lo	0.02	0.05	2.44	2	160	10	17	450	3.4	78	-
BLOCK "B" (N=13)	$\bar{x}$	0.11	0.46	11.18	10.9	975	53	45	3012	6.7	497	-
	δ	0.05	0.27	3.98	3.98	446.5	18.9	11.9	1103.8	2.46	126.4	-
	Hi	0.17	0.79	15.30	15	1500	90	58	4400	9.5	780	-
	Lo	0.02	0.03	2.88	3	160	20	17	750	1.6	290	-
SHERLETT LAKE (N=15)	$\bar{x}$	0.05	0.32	3.20	1.9	52	24	40	189	2.75	543	-
	δ	0.01	0.13	1.55	0.26	25.5	11.2	12.6	84.5	0.86	245.3	-
	Hi	0.07	0.66	7.50	2	100	40	69	330	4.3	1300	-
	Lo	<0.02	<0.03	1.64	1	10	10	10	50	0.9	260	-

(*) The order of tabulation has been changed in order to facilitate progression from source to background.
 (**) Symbols as follows: $\bar{x}$ = mean; δ = standard deviation; Hi = largest value; Lo = smallest value.

TABLE 7: Rank and Similarity ($\alpha = 0.05$) of Sherridon Area Lake Sediment Metal Concentrations⁽¹⁾

<u>METAL</u>	<u>RANK AND SIMILARITY(2)</u>
MERCURY (DRY WT.)	<u>C B A S</u>
ARSENIC	<u>B C A S</u>
CADMIUM	<u>C B A S</u>
COPPER	<u>C B A S</u>
LEAD	<u>B C A S</u>
NICKEL	<u>B S A C</u>
ZINC	<u>C B A S</u>
IRON	<u>C A B S</u>
MANGANESE	<u>S B A C</u>

(1) Per Duncans Multiple Range Test ($\alpha = 0.05$).

(2) Lakes are ranked from highest to lowest means, where
S = Sherlett Lake, C = Camp Lake, A = Cold Lake Block "A"
and B = Cold Lake Block "B". Statistically similar lakes
are underscored.

The order of rank (Table 7) for all metals excepting mercury and iron indicated that Block "B" sediment concentrations were significantly greater than those of Block "A". This condition was likely not a natural artifact due to the proximity of Block "A" to "B". The data suggested that Camp Lake effluent, a major drainage to the north basin of Cold Lake, was effectively removing metals from Block "A" sediments and then depositing these metals in the vicinity of Block "B".

This mechanism presupposes three criteria: a) that the surface of the tailings were relatively stable and do not presently contribute large amounts of metal laden particulates to the water column; thereby minimizing metal laden particulate deposition within Block "A"; b) that effluent waters were acidic and hence able to mobilize metals; and c) that water column nutrient concentrations were insufficient to promote algal blooms and subsequent metal immobilization via the mechanism discussed by Jackson (1978). As previously discussed, each of these criteria were met.

Metals which were present in the tailings at relatively high concentrations and which evidenced significant transport and loadings to Cold Lake included copper, iron and zinc. Copper and zinc concentrations were greatest in Camp Lake sediments but no significant difference in mean concentrations was observed between Camp and either of the Cold Lake sampling blocks. However, Block "B" concentrations of both copper and zinc were significantly

greater than those of Block "A". This suggested that continued discharge of low pH (highly acidic) waters would result in an ever expanding area of sediment loading (of copper and zinc) in a manner somewhat analagous to a wave. This has been termed the "wave effect". Camp Lake iron concentrations were significantly greater than either of the Cold Lake sampling blocks but no significant difference was observed between blocks "A" and "B". This suggested that substantial iron loadings to Cold Lake via the Camp Lake outfall were still occurring and that the "wave effect" had not yet fully developed. Although sediment concentrations of copper, iron and zinc appeared to present few difficulties regarding acute toxicity to benthic organisms (McKee and Wolfe, 1963), literature describing similar situations nearby suggests that chronic exposure would result in considerably reduced productivity and diversity (Crowe, 1972; Hughes, 1976). This has obvious negative implications for resident fish populations.

Arsenic and lead, though not particularly abundant in the ores processed at Sherridon, nevertheless appeared to have been concentrated to a minor degree in the tailings. The sum of both tailings leachate and initial background levels appeared to have culminated in a "wave effect" due to the discharge of low pH waters from Camp Lake. This was particularly evident with lead as Block "B" concentrations were significantly greater than those of Camp Lake, Sherlett Lake and Block "A". The case of arsenic was less clearly defined, as significant overlap between sampling blocks

(excepting Sherlett Lake) was observed. The mean block concentrations observed, however, did not appear sufficient to impose a great deal of stress upon benthic organisms.

Nickel concentrations were low at all sampling blocks. However, the "wave effect" was again evident. Because source (tailings) concentrations were very low, only minor amounts of nickel were apparently loaded to Camp Lake. The acidic waters appeared to have effectively scrubbed Camp Lake sediments, and, to a lesser extent, those of Block "A". Nickel thus mobilized subsequently became sedimented in the vicinity of Block "B".

Mercury and cadmium concentrations were lower than that of nickel. Although the data was again suggestive of a "wave effect", the minimal concentrations observed could have produced an effect more apparent than real.

Lacustrine sediment manganese concentrations are generally found to bear a directly proportional relationship to water column pH levels (Fairbridge, 1972). As such, they can be used as an indication of the severity of water column pH variations (IBID). Manganese concentrations within sediments of the study area proved no exception. Areas subject to significant reduction in pH levels (Camp Lake and Block "A") were found to have significantly lower sediment manganese concentrations than either Block "B" or Sherlett Lake. Manganese concentrations had no direct implications for biota of the study area.

FISH

General meristic information and muscle tissue metal concentrations for fish of Sherlett and Cold Lakes are detailed in Appendices 3(a-g) and 4(a-d), respectively and summarized in Tables 8 and 9, respectively. Appendix 5 details the results of gill netting efforts. Intersite comparisons of muscle tissue concentrations are detailed in Table 10.

(a) Distribution

Net set results (Appendix 5) provided direct evidence of impact upon resident fish populations. Catch per unit effort averaged 0.71 fish per metre of net on Sherlett Lake and only 0.15 fish per metre of net on Cold Lake. Additionally, recent fisheries surveys of Kissinging Lake (Schlick, 1977) yielded an average of 0.51 fish per metre of net of mesh sizes similar to those used in the present study^{*}. Since Schlick's (1977) surveys utilized nets of 1.9 m depth (compared to 3.7 m and 4.9 m depth nets used in the present study) and set locations which included deep water (hence normally less productive)areas, it was reasonable to conclude that nets of the present study fished the water column in a more efficient manner. Thus the Cold Lake portion of Kissinging Lake appeared at least 70% less productive of large sized fish species than did the remainder of Kissinging Lake.

(*) Schlick's (1977) nets of 3 3/4 and 4 1/4 inch mesh are comparable to our 95 mm and 105 mm mesh.

The pre mining distribution of fish within Cold Lake has not been documented. However, discussions with long time residents revealed that the area subjected to gillnetting in the present study had included popular and productive "pickerel holes" for anglers prior to the 1940's (P. Benyk, Sr., and D. Hatch; pers. comm.). Currently, little or no angling effort is expended in the area (W. Angus, and P. Johnson; pers. comm.)^{*}. This tended to confirm that the productivity differential noted earlier was a recent development and was not an historical artifact.

The reduction of fish abundance in Cold Lake and the physicochemistry of the Camp Lake effluent appeared to be unrelated. Although mean pH values and mean copper and zinc concentrations encountered within the Cold Lake sampling blocks are reportedly not acutely toxic (Rahel and Magnusson, 1983; Spear and Pierce, 1979; and Pierce, 1981), mean pH values of Block "A" were near the lower limits for lakes in which species such as walleye, northern pike and cisco occur naturally (Rahel and Magnusson, 1983). Thus it seemed that fish have reacted to the stressful conditions by simple avoidance of the area.

(*) Intensive efforts by study crew members produced only 3 northern pike from Cold Lake after 17 hours combined angling effort. Combined angling effort for 6 hours on Sherlett Lake yielded 13 northern pike, 1 walleye and 2 yellow perch.

b) Metals

A primary consideration respecting fish muscle tissue metal concentrations concerns the implications for human consumption. Excepting mercury levels in Sherlett Lake walleye, mean metal concentrations in fish from both Sherlett and Cold Lakes were well below federal limits pertaining to commercial sale of fish in Canada (Tables 8 and 9)^{*}. Mean mercury concentrations in Sherlett Lake walleye (0.64 ug/g) were observed to exceed the federal limit of 0.50 ug/g. However, both the relative magnitude of the standard error ($\delta=0.29$) and the small sample size ($N=8$) suggested that the data could have been anomalous. Sherlett Lake northern pike, a species usually bearing mercury body burdens greater than or equal to walleye, did not have excessive muscle tissue mercury concentrations.

Muscle tissue metal levels can also be utilized as an indicator of the relative severity of water column metal contamination. This avenue of investigation is particularly useful when applied to small systems virtually closed to fish immigration. It becomes less useful when applied to open systems whereby unrestricted immigration and emmigration by fish can significantly bias the results. Although Sherlett Lake is a system essentially closed to immigration, the configuration of Cold Lake permits unrestricted passage by fish to Kissinging Lake proper. Thus muscle tissue levels for Cold Lake fish must be viewed in a subjective manner open to broad interpretations.

(*) Federal Industry Services Branch limits for some metals applying to commercial sale of fish in Canada:

As	5.0 ug/g	Zn	100 ug/g	Mn	- no limit yet established
Cu	100 ug/g	Pb	10 ug/g	Cd	- no limit yet established
Hg	0.5 ug/g			Cr	- no limit yet established

TABLE 8: Summarization of General Meristics and Muscle Tissue Metal Concentrations for Sherlett Lake Fish.

GENERAL MERISTICS					MUSCLE TISSUE METAL CONCENTRATIONS ($\mu\text{g/g}$)									
Species	Statistic*	Length (cm)	Weight (g)	Sex (M:F)	Age (Yr.)	Hg	As	Cd	Cu	Pb	Mn	Zn	T-Cr	
Northern Pike (N=20)	$\bar{x}$	42.7	537	1.22	5.2	0.22	0.03	<0.1	0.3	0.5	<0.5	4.4	<0.5	
	δ	4.34	126.0		0.81	0.17	0.017	0	0.12	0.07	0	0.69	0	
	Hi	48.1	800		7	0.46	0.08	<0.1	0.5	0.8	<0.5	5.7	<0.5	
	Lo	29.8	220		3	<0.02	<0.01	<0.1	<0.1	<0.5	<0.5	3.0	<0.5	
Common Sucker (N=20)	$\bar{x}$	41.0	1105	0.54	7.9	0.10	0.02	<0.1	0.5	0.6	<0.5	3.6	<0.5	
	δ	3.69	301.0		2.60	0.069	0.007	0	0.50	0.12	0	0.71	0	
	Hi	48.1	1720		13	0.27	0.03	<0.1	2.5	0.8	<0.5	5.5	<0.5	
	Lo	34.1	660		5	0.05	<0.01	<0.1	0.2	<0.5	<0.5	2.7	<0.5	
Walleye (N=20)	$\bar{x}$	40.2	749	0.33	9.0	0.64	0.03	<0.1	0.2	<0.5	<0.5	3.8	<0.5	
	δ	3.80	170.4		2.07	0.29	0.017	0	0.076	0	0	0.48	0	
	Hi	47.1	1020		12	1.17	0.07	<0.1	0.3	<0.5	<0.5	4.2	<0.5	
	Lo	36.2	520		6	0.27	0.02	<0.1	0.1	<0.5	<0.5	3.0	<0.5	
Cisco (N=8)	$\bar{x}$	39.0	1017	0.82	12.2	0.16	0.04	<0.1	0.6	0.6	<0.5	4.5	<0.5	
		1.88	151.4		3.79	0.039	0.014	0	0.19	0.20	0	0.88	0	
	Hi	41.8	1220		21	0.23	0.08	<0.1	0.9	1.2	<0.5	6.9	<0.5	
	Lo	34.3	650		5	0.08	0.02	<0.1	0.2	<0.5	<0.5	3.4	<0.5	
Whitefish (N=1)	$\bar{x}$	40.7	1180	M	4	0.09	0.13	<0.1	0.3	<0.5	<0.5	3.5	<0.5	
	Hi	52.0	1320	M	7	0.19	0.04	<0.1	0.4	<0.5	<0.5	7.2	<0.5	
	Lo	51.0	1100	M	6	0.13	0.04	<0.1	0.4	<0.5	<0.5	6.2	<0.5	
Burbot (N=2)	$\bar{x}$	23.2	200	F	9	0.17	0.1	<0.1	0.3	<0.5	<0.5	4.7	<0.5	
	Hi	23.2	180	M	7	0.06	<0.1	<0.1	0.2	<0.5	<0.5	4.3	<0.5	
	Lo													

(*) Symbols as follows: $\bar{x}$ = mean; δ = standard deviation; Hi = largest value; Lo = smallest value.

TABLE 9: Summarization of General Meristics and Muscle Tissue Metal Concentrations for Cold Lake Fish.

GENERAL MERISTICS					MUSCLE TISSUE METAL CONCENTRATIONS ($\mu\text{g/g}$)								
Species	Statistic*	Length (cm)	Weight (g)	Sex (M:F)	Age Yr.	Hg	As	Cd	Cu	Pb	Ni	Zn	T-Cr
Northern Pike (N=7)	$\bar{x}$	55.7	1167	0.75	7.4	0.22	0.02	<0.1	0.5	0.7	<0.5	6.2	<0.5
	δ	7.07	367.8		1.72	0.08	0	0	0.18	0.15	0	2.20	0
	Hi	66.8	1560		10	0.35	0.02	<0.1	0.9	0.8	<0.5	10.9	<0.5
	Lo	47.5	660		5	0.13	0.02	<0.1	0.3	<0.5	<0.5	4.8	<0.5
Common Sucker (N=20)	$\bar{x}$	38.0	762	0.25	8.6	0.04	0.01	<0.1	0.5	0.6	<0.5	4.3	<0.5
	δ	1.95	104.6		2.04	0.019	0.003	0	0.32	0.28	0	0.83	0
	Hi	41.7	920		12	0.08	0.02	<0.1	1.4	1.7	<0.5	6.2	<0.5
	Lo	33.8	540		6	0.02	<0.01	<0.1	0.2	<0.5	<0.5	2.9	<0.5
Walleye (N=9)	$\bar{x}$	41.7	871	2.0	5.9	0.14	0.02	<0.1	0.3	0.5	<0.5	5.3	<0.5
	δ	4.36	310.2		0.93	0.04	0.01	0	0.19	0.10	0	1.53	0
	Hi	50.2	1560		8	0.19	0.04	<0.1	0.7	0.8	<0.5	8.6	<0.5
	Lo	36.0	600		5	0.05	<0.01	<0.1	0.2	<0.5	<0.5	3.8	<0.5
Cisco (N=2)	Hi	33.6	520	M	9	0.22	0.03	<0.1	0.7	0.8	<0.5	4.8	<0.5
	Lo	33.3	500	M	7	0.04	0.03	<0.1	0.5	<0.5	<0.5	4.2	<0.5

(*) Symbols as follows: $\bar{x}$ = mean; δ = standard deviation; Hi = largest value; Lo = smallest value.

Comparisons were drawn between Cold Lake and Sherlett Lake fish metal concentrations in order to identify metals which may have bioaccumulated at rates above normal study area background. Metal concentrations in fish from the study area were then put into perspective by comparison to two separate systems (Table 10). Wekusko Lake data (Brown et al, 1980) was used because of extensive arsenic, copper, lead, zinc and other mineralizations and related mining activity within the immediate watershed (Davies et al, 1962). Data from Gods Lake was also compared because the lake is generally considered a pristine environment subject to little anthropogenic impact other than minor arsenic loading (Beck, 1982).

One primary consideration involved the propriety of considering Sherlett Lake data as background. Comparison to Gods Lake suggested no significant difference in bioaccumulation rates of all metals excepting arsenic. The significantly greater arsenic level in Gods Lake fish was attributed in part to minor anthropogenic loading via the abandoned Gods Lake Gold Mines operation. Thus it appeared that Sherlett Lake was indistinguishable from Gods Lake and could therefore be considered a pristine environment.

TABLE 10: Comparisons ($\alpha=0.05$) of Muscle Tissue Metal Concentrations Between Fish From Sherlett, Cold Wekusko and Gods Lakes

LAKE vs LAKE	SPECIES	LAKE ¹ WITH SIGNIFICANTLY GREATER CONCENTRATION ($t \alpha = 0.05$)						
		As	Cd	Cu	Hg	Ni	Pb	Zn
Sherlett vs Cold	Northern Pike	Sh	--	Co	--	--	Co	Co
	Common Sucker	Sh	--	--	Sh	--	--	Co
	Walleye	--	--	--	Sh	--	--	Co
Sherlett vs Wekusko ²	Northern Pike	We	--	We	--	We	We	WE
	Common Sucker	We	--	--	--	We	We	--
	Walleye	We	--	We	Sh	We	WE	--
Sherlett vs Gods ³	Northern Pike	Go	--	--	--	--	--	--
	Common Sucker	Go	--	--	Go	--	Sh	--
	Walleye	Go	--	--	--	--	--	Go
Cold vs Wekusko ²	Northern Pike	We	--	--	--	We	--	--
	Common Sucker	We	--	--	We	We	--	--
	Walleye	We	--	--	We	We	We	Co
Cold vs Gods	Northern Pike	Go	--	Co	--	--	Co	--
	Common Sucker	Go	--	--	Go	--	--	--
	Walleye	Go	--	--	Go	--	--	--

(1) Lake symbols as follows: Sh = Sherlett Lake; Co = Cold Lake; We = Wekusko Lake; Go = Gods Lake; -- = No Significant Difference

(2) Means for this lake were extracted from Brown et al, (1980).

(3) Means for this lake were extracted from Beck, (1982). Northern pike and walleye data were extracted from Block "B", the north basin of Gods Lake. Common sucker data was extracted from Block "A", the south basin of Gods Lake. This latter was due to insufficient samples from Block "B".

Comparisons to Wekusko Lake, which has been subject to loadings from both natural geological occurrences (like Sherlett) and anthropogenic sources (unlike Sherlett), produced distinctly different results. Wekusko Lake fish concentrations of arsenic, nickel, lead and possibly copper were significantly greater than those of Sherlett Lake. No consistently detectable significant differences were observed for cadmium, mercury and zinc concentrations. The absence of significant differences in zinc concentrations was not anticipated because of the intensity of zinc mining activity in the immediate watershed of Wekusko Lake. The probable explanation for this apparent anomaly lies within the relative trophic status of the two lakes. Sherlett, considered oligo-mesotrophic, was less productive (hence had less plankton) than Wekusko, which was a meso-eutrophic lake (Brown et al, 1980). Because plankton greatly accelerate the rate of zinc sedimentation (Jackson, 1978), the bioavailability to fish of Wekusko water column zinc was probably reduced to levels near that of Sherlett. Thus, bioaccumulations attributable to anthropogenic loadings were readily identifiable by comparison to Sherlett Lake fish.

Comparisons between Sherlett and Cold data indicated that only zinc showed a significantly greater rate of bioaccumulation in Cold Lake fish. Excluding zinc, this closely mirrored the results of the Cold-Gods comparison). This implied a direct cause-effect relationship between zinc concentrations in Camp Lake discharges and the zinc body burden of Cold Lake fish. Although in the absence of site specific historical data a case could be made for the view that

the fish sampled were recent immigrants from Kississing Lake proper and thus were a product of circumstances beyond the zone of influence from Camp Lake discharges, the author's inclination was to accept the former view. Cold Lake fish zinc concentrations were, however, not significantly different from either Wekusko or Gods Lake fish. Thus serious degradation of fish was not necessarily implied.

CONCLUSIONS

It was concluded that:

1. Sherlett Lake was a pristine system in which no detectable anthropogenic impacts were observed;
2. Sherlett Lake waters constituted an excellent potable water supply source as the water quality was within objective guidelines established by the Federal-Provincial Working Group on Drinking Water;
3. Camp Lake was a seriously impacted lake in that the water quality was hostile to most macroscopic aquatic life forms native to the study area;
4. Degradation of Camp Lake water quality was due to leachate and other materials emanating from the adjacent tailings disposal site of the abandoned Sherridon mine and mill operation;
5. Metals and acid loadings from Camp Lake discharges were significantly impacting upon Cold Lake water quality, sediments and fish distribution;
6. Discharges from Camp Lake will continue to impact upon Cold Lake water quality, sediments and fish distribution;
7. Cold Lake waters constituted an acceptable potable water supply source as the water quality (excepting turbidity) was within objective quality guidelines established by the Federal-Provincial Working Group on Drinking Water.

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APPENDIX I(a): Water Physicochemical Data for Sherlett Lake, June 21, 1982^a

PARAMETERS	SAMPLE STATIONS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Field Temperature (°C)	17.0	15.8	11.0	17.0	12.1	17.2	17.0	17.1	16.9	16.3	15.8	11.2	15.0	15.0	11.2
Conductivity (µS/cm)	64.1	64.1	62.2	63.3	63.3	61.2	60.5	60.1	60.1	60.1	61.2	59.7	58.7	59.7	59.7
Residue Non Filtr.	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
pH	7.50	7.40	7.15	7.60	7.50	7.50	7.50	7.45	7.50	7.50	7.50	7.40	7.50	7.45	7.05
Alkalinity Total (CaCO ₃) (mg/L)	23.0	23.0	22.0	23.0	24.0	22.0	24.0	23.0	23.0	23.0	24.0	23.0	23.0	23.0	23.0
Alkalinity (HCO ₃) (mg/L)	28.1	28.1	26.8	28.1	29.3	26.9	29.3	28.1	28.1	28.1	29.3	28.1	28.1	28.1	28.1
Alkalinity (CO ₃) (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkalinity (OH) (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dissolved Oxygen (mg/L)	10.4	9.9	9.5	9.5	9.8	10.0	9.7	9.9	9.8	9.8	9.9	8.9	9.8	9.8	7.8
T.O.C. (mg/L)	17.0	15.5	15.5	16.0	15.5	17.0	17.0	16.0	17.0	16.0	16.0	16.0	16.0	16.0	16.0
T.T.C. (mg/L)	5.0	4.5	4.5	4.0	4.5	4.5	4.0	4.0	4.0	4.0	4.5	5.5	4.5	4.0	6.5
Turbidity (NTU)	0.90	0.95	0.95	0.95	0.85	1.0	0.85	0.85	0.90	0.85	0.75	0.85	0.85	0.80	0.85
Rjeidhal Total N (mg/L)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
NO ₃ NO ₂ N(Diam.) (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P Total (mg/L)	0.014	0.011	0.018	0.015	0.012	0.015	0.012	0.012	0.018	0.016	0.014	0.013	0.012	0.014	0.017
Cyanide (Free) (mg/L)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
As (Kst.) (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd (Kst.) (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cu (Kst.) (mg/L)	0.01	0.07	0.01	0.01	<0.005	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pb (Kst.) (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni (Kst.) (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn (Kst.) (mg/L)	<0.01	0.02	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ca (Kst.) (mg/L)	6.99	7.03	7.00	7.00	7.05	7.05	7.05	7.02	6.98	7.00	7.31	7.01	6.97	7.11	6.99
Mg (Kst.) (mg/L)	2.22	2.20	2.18	2.20	2.20	2.22	2.22	2.22	2.21	2.20	2.23	2.16	2.17	2.19	2.16
Sample Depth (m)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sample Depth (m)	2.13	0.48	3.96	3.55	3.21	0.8	0.54	0.1	1.62	1.57	0.53	4.1	1.24	4.27	5.18
Total Depth (m)	5.2	2.8	5.2	5.0	5.1	3.3	2.4	3.2	3.1	3.4	4.9	5.4	3.1	7.0	6.65

^a Sample Stations as per Figure 2

APPENDIX 1(b): Water Physicochemical Data for Camp Lake, June 20, 1982*

PARAMETERS	SAMPLE STATIONS															28	29	30
Field Temperature	16.5	16.0	16.8	16.8	16.7	17.2	16.8	17.0	16.5	16.5	16.5	10.7	17.1	14.0	18.0			
Conductivity	171	167	167	157	170	112	166	197	166	165	599	254	131	189	104			
Residue Non Filtr.	5	10	10	9	8	14	12	24	6	7.0	24	<5	14	10	9			
pH	4.00	4.10	4.05	4.15	4.05	5.30	4.10	3.90	4.15	4.10	3.20	3.65	5.00	4.05	6.30			
Alkalinity Total(CaCO ₃)	0.0	0.0	0.0	0.0	0.0	3.00	0.0	0.0	0.0	0.0	0.0	0.0	3.00	0.0	6.00			
Alkalinity (HCO ₃)	0.0	0.0	0.0	0.0	0.0	3.66	0.0	0.0	0.0	0.0	0.0	0.0	3.66	0.0	7.32			
Alkalinity (CO ₃)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Alkalinity (OH)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Dissolved Oxygen	7.6	7.8	8.3	7.9	7.6	8.3	7.8	7.6	7.7	7.8	10.2	7.5	8.0	7.8	8.8			
T.O.C.	8.0	8.5	8.0	8.5	8.0	11.0	8.0	9.5	8.5	8.0	6.0	6.0	10.0	7.5	11.5			
T.T.C.	1.5	1.0	<1.0	<1.0	<1.0	1.0	<1.0	1.0	<1.0	1.0	2.0	1.0	1.0	<1.0	1.5			
Turbidity	6.0	7.0	8.5	9.0	7.0	10.0	8.0	5.5	9.0	7.5	35.0	7.0	10.0	8.0	7.5			
Kjeldhal Total N	0.20	0.40	0.20	0.30	0.20	0.40	0.30	0.20	0.20	0.20	0.40	0.20	0.70	0.20	0.30			
NO ₃ NO ₂ N (Diss.)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	<0.01	0.01			
P Total	0.004	0.005	0.006	0.006	0.004	0.009	0.006	0.007	0.005	0.005	0.004	0.003	0.009	0.004	0.012			
Cyanide (Free)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02			
As (Ext.)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
Cd (Ext.)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005			
Cu (Ext.)	0.06	0.07	0.08	0.06	0.06	0.14	0.06	0.06	0.06	0.06	0.16	0.11	0.05	0.06	0.04			
Pb (Ext.)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005			
Mn (Ext.)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005			
Zn (Ext.)	0.34	0.31	0.32	0.28	0.32	0.23	0.30	0.30	0.31	0.31	0.76	0.49	0.23	0.36	0.20			
Ca (Ext.)	10.5	10.3	10.3	10.1	10.4	9.7	10.2	10.6	10.3	10.3	16.8	11.2	9.75	10.5	9.38			
Mg (Ext.)	4.30	4.16	4.17	4.05	4.20	3.66	4.12	4.44	4.15	4.17	8.70	4.76	3.78	4.29	3.51			
Hg (Ext.)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02			
Sample Depth	1.6	3.8	1.5	2.7	1.5	4.9	2.4	2.4	2.7	4.5	6.3	4.0	2.4	2.7	0.8			
Total Depth	5.9	5.7	2.9	4.1	6.0	8.1	7.9	3.4	4.6	5.2	9.1	5.5	3.4	3.0	6.6			

* Sample Stations as per Figure 3

APPENDIX 1(c): Water Physicochemical Data for Cold Lake Block "A", June 20, 1982^a.

PARAMETERS	SAMPLE STATIONS														
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Field Temperature			(°C)												
Conductivity	14.7	16.0	16.1	15.1	14.2	14.5	14.8	15.8	15.5	15.2	15.1	15.5	16.1	15.0	15.5
Residue Non Filtr.	111	123	172	109	110	112	110	164	146	113	110	108	141	157	113
pH	<5	7	<5	<5	6	8	8	11	10	6	7	7	6	6	<5
Alkalinity Total(CaCO ₃)	6.35	5.20	4.10	6.55	6.55	6.20	6.40	4.15	4.40	6.15	6.45	6.45	4.55	4.35	6.20
Alkalinity (HCO ₃)	6.00	2.00	0.0	7.00	7.00	6.00	7.00	0.0	0.0	5.00	6.00	9.00	1.00	0.0	5.00
Alkalinity (CO ₃)	7.32	2.44	0.0	8.54	8.54	7.32	8.54	0.0	0.0	6.10	7.32	11.00	1.22	0.0	6.10
Alkalinity (OH)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dissolved Oxygen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T.O.C.	10.4	9.7	8.9	10.5	10.2	10.4	10.0	9.1	9.5	10.1	9.9	10.1	9.3	9.4	10.1
T.I.C.	9.0	9.0	7.0	9.1	9.0	9.0	9.5	8.5	8.5	9.0	9.5	9.5	8.0	8.0	9.0
Turbidity	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Kjeldhal Total N	2.0	3.5	5.0	2.0	2.0	2.5	2.5	5.0	4.5	3.0	2.0	2.0	4.5	5.0	2.5
NO ₃ NO ₂ N (Diss.)	0.10	0.20	0.20	0.20	0.30	0.20	0.25	0.25	0.20	0.20	0.20	0.20	0.20	0.20	0.20
P Total	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02
Cyanide (Free)	0.004	0.007	0.004	0.010	0.007	0.006	0.008	0.004	0.005	0.007	0.006	0.006	0.005	0.005	0.006
As (Ext.)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cd (Ext.)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cu (Ext.)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pb (Ext.)	0.03	0.03	0.06	0.06	0.02	0.03	0.08	0.06	0.04	0.03	0.02	0.04	0.20	0.08	0.03
Mn (Ext.)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn (Ext.)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ca (Ext.)	0.18	0.23	0.34	0.17	0.16	0.18	0.18	0.32	0.27	0.19	0.16	0.16	0.28	0.28	0.18
Mg (Ext.)	9.18	9.60	10.3	9.09	9.03	9.26	9.14	10.1	9.77	9.26	9.01	8.96	9.80	9.86	9.16
Hg (Ext.)	3.80	3.80	4.27	3.54	3.51	3.62	3.56	4.11	3.93	3.63	3.51	3.49	3.89	3.98	3.59
Sample Depth	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Depth	3.7	0.5	1.5	3.1	2.9	0.5	4.1	2.0	2.0	0.05	2.7	4.5	0.3	4.0	1.5
	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
	6.6	2.0	2.0	5.2	7.0	0.9	4.5	2.8	2.4	5.1	3.05	5.0	2.3	4.5	2.8

^a Sample Stations as per Figure 3

APPENDIX 1(d): Water Physicochemical Data for Cold Lake Block "B", June 20, 1982.

PARAMETERS

SAMPLE STATIONS

	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Field Temperature (°C)	16.0	15.0	15.2	15.5	16.0	15.5	15.7	10.2	15.2	10.0	15.0	15.3	16.0	14.2	15.4
Conductivity (µS/cm)	104	105	106	105	105	105	105	99.6	<5	99.6	107	105	105	104	105
Residue Non Filtr.	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
pH	7.00	6.75	6.90	7.05	7.00	7.00	6.95	6.95	<5	6.80	6.90	7.05	7.10	7.00	7.05
Alkalinity Total (CaCO ₃) (mg/L)	10.0	9.0	9.0	11.0	10.0	10.0	10.0	14.0	<5	14.0	9.0	10.0	11.0	10.0	10.0
Alkalinity (HCO ₃) (mg/L)	12.2	11.0	11.0	13.4	12.2	12.2	12.2	17.1	<5	17.1	11.0	12.2	13.4	12.2	12.2
Alkalinity (CO ₃) (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkalinity (OH) (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dissolved Oxygen (mg/L)	10.1	10.1	10.1	10.1	10.1	9.9	10.1	9.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T.O.C. (mg/L)	10.0	10.0	9.5	10.0	10.5	10.0	9.5	9.5	10.5	9.0	9.1	9.7	9.8	9.8	10.2
T.T.C. (mg/L)	1.5	1.5	1.0	1.0	1.0	1.0	1.0	2.0	1.0	3.0	1.0	1.0	1.0	1.5	1.5
Turbidity (NTU)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0.95	1.0	1.5	1.5	1.5	1.5	1.5
Kjeldhal Total N (mg/L)	0.30	0.35	0.40	0.35	0.30	0.35	0.35	0.4	0.35	0.35	0.30	0.30	0.30	0.30	0.30
NO ₃ NO ₂ N (Diss.) (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01
P Total (mg/L)	0.011	0.008	0.007	0.008	0.009	0.008	0.010	0.009	0.009	0.009	0.009	0.008	0.009	0.009	0.010
Cyanide (Free) (mg/L)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
As (Ext.) (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd (Ext.) (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cu (Ext.) (mg/L)	0.04	0.07	0.04	0.04	0.04	0.03	0.19	0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pb (Ext.) (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni (Ext.) (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn (Ext.) (mg/L)	0.13	0.15	0.14	0.13	0.13	0.13	0.17	0.11	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ca (Ext.) (mg/L)	8.80	8.81	8.75	8.94	8.68	8.78	8.81	8.46	9.60	8.34	8.71	8.70	8.74	8.57	8.67
Mg (Ext.) (mg/L)	3.40	3.40	3.38	3.46	3.35	3.39	3.40	3.25	3.70	3.70	3.37	3.36	3.38	3.30	3.36
Na (Ext.) (mg/L)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sample Depth (m)	2.9	5.6	1.2	1.4	0.4	0.7	2.5	7.2	4.5	8.2	3.1	2.3	0.28	5.9	0.5
Total Depth (m)	5.9	6.5	3.05	9.5	2.2	1.1	5.45	9.1	9.0	9.5	9.6	9.2	3.65	9.0	3.2

* Sample Stations as per Figure 3

APPENDIX 2(a): Metal Concentrations in Sherlett Lake Sediments

STATION NUMBER	Hg WET(ug/g)	Hg DRY(ug/g)	As (ug/g)	Cd (ug/g)	Cu (ug/g)	Pb (ug/g)	Ni (ug/g)	Zn (ug/g)	Po (%)	Mn (ug/g)
1	0.06	0.34	2.38	2	86	40	46	320	3.3	480
2	<0.02	<0.03	1.64	1	10	10	10	50	0.9	260
3	0.06	0.41	5.71	2	95	40	50	330	2.8	470
4	0.05	0.36	3.57	2	72	40	42	260	2.6	420
5	0.07	0.66	4.14	2	100	40	46	320	2.8	440
6	0.05	0.36	2.37	2	48	30	42	160	2.5	520
7	0.05	0.27	2.36	2	40	10	33	130	1.8	320
8	0.06	0.37	1.95	2	38	10	33	130	2.2	430
9	0.05	0.25	2.24	2	29	20	29	120	1.9	400
10	0.05	0.29	2.84	2	55	20	46	190	2.6	500
11	0.06	0.30	7.50	2	44	20	46	220	4.3	1300
12	0.06	0.20	3.18	2	37	20	38	150	3.5	720
13	0.06	0.29	2.67	2	38	20	38	150	3.7	620
14	0.06	0.31	2.76	2	42	20	38	190	3.6	720
15	0.06	0.32	2.70	2	40	20	69	120	2.8	540

APPENDIX 2(b): Metal Concentrations in Camp Lake Sediments

STATION NUMBER	Hg WET(ug/g)	Hg DRY(ug/g)	As (ug/g)	Cd (ug/g)	Cu (ug/g)	Pb (ug/g)	Mn (ug/g)	Fe (%)	Zn (ug/g)	Mn (ug/g)
16	0.05	0.77	6.83	16	920	20	33	36.0	5400	100
17	0.06	0.42	8.13	39	1400	40	38	27.0	18000	160
18	0.07	1.75	8.71	5	540	20	17	43.0	1100	110
19	0.15	2.42	13.4	3	340	40	17	37.0	700	100
20	0.16	1.64	13.0	37	3000	60	33	29.0	15000	200
21	0.05	0.56	5.07	3	160	20	17	41.0	350	85
22	0.19	1.91	28.8	3	410	60	20	38.0	750	880
23	<0.02	<0.50	6.84	2	220	20	17	36.0	300	66
24	0.04	0.50	5.43	6	6000	20	20	32.0	1500	76
25	0.11	1.38	9.61	8	690	30	20	41.0	1400	100
26	0.05	0.58	4.43	3	240	30	20	38.0	750	140
27	0.08	0.72	8.61	11	900	30	33	42.0	2600	82
28	0.07	0.43	6.50	3	230	20	23	40.0	350	120
29	0.20	1.41	11.5	9	1400	30	29	38.0	2000	130
30	0.27	2.08	16.4	19	1900	40	33	28.0	4400	220

APPENDIX 2(c): Metal Concentrations in Cold Lake Block "A" Sediments

STATION NUMBER	WET(ug/g)	Hg DRY(ug/g)	As (ug/g)	Cd (ug/g)	Cu (ug/g)	Pb (ug/g)	Ni (ug/g)	Zn (ug/g)	Fe (%)	Mn (ug/g)
31	0.23	0.81	11.20	8	1400	40	38	2500	10.0	340
32	-	-	-	-	-	-	-	-	-	-
33	0.08	0.21	6.35	3	450	30	20	1200	14.0	160
34	0.17	0.33	10.70	5	820	30	33	1900	7.0	340
35	0.26	1.46	11.00	15	1600	40	38	3400	9.4	360
36	0.06	0.11	4.17	2	210	10	33	500	3.4	150
37	0.05	0.08	7.50	3	320	20	25	1300	7.6	420
38	0.05	0.28	5.13	3	430	20	25	900	42.0	78
39	0.05	0.38	8.55	13	710	30	54	3300	11.0	160
40	0.20	0.85	7.27	8	880	40	42	1800	5.3	280
41	0.03	0.05	4.29	2	280	20	42	680	5.2	160
42	0.08	0.19	10.10	3	420	30	33	900	15.0	360
43	0.02	0.14	2.44	2	160	20	29	450	4.0	190
44	0.08	0.22	6.63	4	440	20	25	1000	12.0	130
45	0.05	0.07	3.86	2	210	20	17	500	5.3	160

APPENDIX 2(d): Metal Concentrations in Cold Lake Block "B" Sediments

STATION NUMBER	Hg WET(ug/g)	Hg DRY(ug/g)	As (ug/g)	Cd (ug/g)	Cu (ug/g)	Pb (ug/g)	Ni (ug/g)	Zn (ug/g)	Fe (%)	Mn (ug/g)
46	0.12	0.48	10.60	8	730	50	50	2400	6.0	610
47	0.10	0.43	15.30	12	940	50	50	3800	9.5	530
48	-	-	-	-	-	-	-	-	-	-
49	0.12	0.60	15.10	14	1400	60	58	4400	7.0	450
50	-	-	-	-	-	-	-	-	-	-
51	0.02	0.03	4.57	4	240	20	17	1100	2.8	310
52	0.05	0.13	8.33	7	520	40	38	2200	6.0	780
53	0.10	0.48	10.90	13	980	60	54	3500	9.0	560
54	0.17	0.79	14.90	13	1200	90	54	3600	6.3	520
55	0.15	0.24	12.30	15	1400	50	46	3800	9.2	450
56	0.13	0.68	11.90	13	1400	60	46	3900	6.8	440
57	0.11	0.59	10.00	14	1200	60	54	3500	8.8	440
58	0.03	0.05	2.88	3	160	20	25	750	1.6	290
59	0.16	0.79	14.0	12	1500	60	46	3000	4.9	520
60	0.16	0.75	14.6	13	1000	70	46	3200	8.5	560

APPENDIX 2(e): Metal and Cyanide Concentrations in Sherridon Tailings.

STATION NUMBER	Hg WET(ug/g)	Hg DRY(ug/g)	As (ug/g)	Cd (ug/g)	Cu (ug/g)	Pb (ug/g)	Ni (ug/g)	Zn (ug/g)	Fe (%)	Mn (ug/g)	CN (ug/g)
A	0.95	1.19	85.6	2	620	210	17	1300	25.0	120	<1.0
B	4.35	5.96	110.0	2	3000	210	17	650	21.0	69	<1.0
C	1.24	1.43	109.0	3	1500	240	25	1700	33.0	100	<1.0
D	2.32	2.67	88.4	2	680	160	17	1700	29.0	79	<1.0

APPENDIX 3(a): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Sherlett Lake Northern Pike

Meristics				Muscle Tissue Metal Levels (ug/g)							
Length (cm)	Weight (g)	Sex	Age (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
44.6	560	F	5	0.32	0.03	<0.1	0.5	<0.5	<0.5	5.1	<0.5
41.4	500	M	6	0.40	0.04	<0.1	0.3	<0.5	<0.5	5.6	<0.5
43.3	590	F	5	0.39	0.02	<0.1	0.2	<0.5	<0.5	4.0	<0.5
42.8	540	M	5	0.35	0.03	<0.1	0.2	<0.5	<0.5	5.0	<0.5
29.8	220	M	3	0.21	0.02	<0.1	0.3	<0.5	<0.5	4.0	<0.5
37.5	440	M	4	0.27	0.03	<0.1	<0.1	<0.5	<0.5	4.5	<0.5
40.0	510	M	5	0.33	<0.01	<0.1	<0.1	<0.5	<0.5	4.5	<0.5
37.0	350	F	5	0.27	<0.01	<0.1	<0.1	<0.5	<0.5	4.0	<0.5
47.2	590	F	5	0.45	0.02	<0.1	0.4	<0.5	<0.5	4.0	<0.5
47.8	770	F	5	0.46	0.05	<0.1	0.3	<0.5	<0.5	3.0	<0.5
43.6	560	M	5	0.44	0.04	<0.1	<0.1	<0.5	<0.5	4.8	<0.5
43.0	460	F	5	<0.02	0.04	<0.1	0.3	0.6	<0.5	5.0	<0.5
45.3	520	M	6	0.06	0.04	<0.1	0.2	<0.5	<0.5	4.0	<0.5
47.3	540	M	7	0.06	0.06	<0.1	0.3	<0.5	<0.5	5.7	<0.5
48.1	800	F	6	0.04	0.03	<0.1	0.3	<0.5	<0.5	4.5	<0.5
42.2	510	M	5	0.06	0.03	<0.1	0.2	<0.5	<0.5	5.0	<0.5
42.2	580	F	5	0.05	0.08	<0.1	0.1	0.8	<0.5	3.5	<0.5
41.2	520	F	5	0.04	0.02	<0.1	0.3	<0.5	<0.5	3.7	<0.5
43.4	520	M	5	0.06	0.04	<0.1	0.5	<0.5	<0.5	4.5	<0.5
46.2	660	M	6	0.06	0.02	<0.1	0.3	<0.5	<0.5	4.0	<0.5

APPENDIX 3(b): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Sherlett Lake Common Sucker

Meristics				Muscle Tissue Metal Levels (ug/g)							
Length (cm)	Weight (g)	Sex	Age (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
48.1	1670	F	8	0.07	0.02	<0.1	0.3	<0.5	<0.5	3.0	<0.5
44.0	1340	M	8	0.06	0.02	<0.1	2.5	<0.5	<0.5	2.7	<0.5
43.7	1310	F	10	0.07	<0.01	<0.1	0.4	0.6	<0.5	4.5	<0.5
36.5	820	F	6	0.08	0.02	<0.1	0.3	0.6	<0.5	3.2	<0.5
45.0	1400	F	11	0.07	0.01	<0.1	0.4	<0.5	<0.5	3.5	<0.5
41.0	1100	M	5	0.05	0.02	<0.1	0.3	<0.5	<0.5	3.5	<0.5
42.5	1300	M	13	0.05	<0.01	<0.1	0.7	<0.5	<0.5	3.2	<0.5
40.4	1040	M	11	0.20	0.02	<0.1	0.5	<0.5	<0.5	4.5	<0.5
39.7	1000	F	6	0.26	<0.01	<0.1	0.3	0.6	<0.5	3.2	<0.5
42.7	1080	F	12	0.27	<0.01	<0.1	0.3	0.6	<0.5	4.0	<0.5
42.0	1320	F	5	0.10	<0.01	<0.1	0.3	<0.5	<0.5	3.2	<0.5
34.1	660	F	5	0.06	0.03	<0.1	0.2	<0.5	<0.5	3.5	<0.5
35.6	740	M	7	0.07	0.01	<0.1	0.4	0.8	<0.5	4.0	<0.5
47.2	1720	F	10	0.17	0.01	<0.1	0.3	0.8	<0.5	4.5	<0.5
36.3	720	F	7	0.06	<0.01	<0.1	0.3	0.8	<0.5	3.5	<0.5
40.8	1100	F	6	0.06	<0.01	<0.1	0.2	0.8	<0.5	3.0	<0.5
41.5	1120	M	10	0.10	0.02	<0.1	0.3	<0.5	<0.5	3.5	<0.5
41.2	1000	F	6	0.06	0.02	<0.1	0.3	<0.5	<0.5	4.0	<0.5
38.0	740	M	5	0.05	0.03	<0.1	0.7	<0.5	<0.5	5.5	<0.5
39.9	920	F	6	0.05	0.02	<0.1	0.2	<0.5	<0.5	2.7	<0.5

APPENDIX 3(c): General Meristics and Muscle Tissue Metal Concentrations (ug/g):
Sherlett Lake Walleye

Meristics				Muscle Tissue Metal Levels (ug/g)							
Length (cm)	Weight (g)	Sex	Age (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
44.1	950	F	10	0.76	0.07	<0.1	0.1	<0.5	<0.5	3.5	<0.5
38.9	660	M	10	0.56	0.02	<0.1	0.1	<0.5	<0.5	3.2	<0.5
41.6	770	F	7	0.83	0.03	<0.1	0.1	<0.5	<0.5	3.7	<0.5
47.1	1020	F	12	1.17	0.04	<0.1	0.3	<0.5	<0.5	4.2	<0.5
39.5	780	F	11	0.67	0.02	<0.1	0.2	<0.5	<0.5	4.2	<0.5
36.7	590	F	6	0.27	0.02	<0.1	0.1	<0.5	<0.5	4.2	<0.5
36.2	520	F	8	0.53	0.02	<0.1	0.1	<0.5	<0.5	3.0	<0.5
37.8	700	M	8	0.33	0.03	<0.1	0.2	<0.5	<0.5	4.0	<0.5

APPENDIX 3(d): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Sherlett Lake Cisco

Meristich				Muscle Tissue Metal Levels (ug/g)							
Length (cm)	Weight (g)	Sex	Age (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
37.8	900	M	NA	0.13	0.03	<0.1	0.7	0.8	<0.5	5.6	<0.5
39.0	980	M	12	0.20	0.02	<0.1	0.9	<0.5	<0.5	6.9	<0.5
38.5	1000	M	14	0.20	0.05	<0.1	0.7	<0.5	<0.5	4.2	<0.5
40.0	1110	M	14	0.18	0.03	<0.1	0.2	<0.5	<0.5	3.6	<0.5
39.0	1080	F	NA	0.15	0.05	<0.1	0.7	<0.5	<0.5	4.4	<0.5
36.6	800	M	NA	0.14	0.05	<0.1	0.7	<0.5	<0.5	5.6	<0.5
39.2	1020	F	8	0.08	0.05	<0.1	0.7	<0.5	<0.5	6.0	<0.5
34.3	650	F	NA	0.08	0.04	<0.1	0.5	<0.5	<0.5	4.0	<0.5
40.0	1090	M	14	0.16	0.02	<0.1	0.5	0.8	<0.5	4.6	<0.5
37.8	1040	F	8	0.16	0.04	<0.1	0.9	0.8	<0.5	4.2	<0.5
40.6	960	F	14	0.21	0.04	<0.1	0.5	0.8	<0.5	3.9	<0.5
39.0	960	F	NA	0.16	0.04	<0.1	0.5	<0.5	<0.5	4.2	<0.5
41.0	1260	M	14	0.14	0.04	<0.1	0.5	<0.5	<0.5	3.9	<0.5
41.8	1200	M	12	0.13	0.06	<0.1	0.5	<0.5	<0.5	4.3	<0.5
36.6	810	F	5	0.14	0.05	<0.1	0.9	<0.5	<0.5	4.1	<0.5
39.9	1100	F	13	0.12	0.04	<0.1	0.2	1.2	<0.5	3.9	<0.5
41.5	1180	F	NA	0.18	0.04	<0.1	0.5	0.8	<0.5	4.7	<0.5
39.0	960	F	10	0.17	0.04	<0.1	0.6	<0.5	<0.5	4.7	<0.5
40.8	1220	F	21	0.23	0.08	<0.1	0.6	0.8	<0.5	3.9	<0.5
37.1	1020	M	12	0.15	0.03	<0.1	0.5	0.8	<0.5	3.4	<0.5

APPENDIX 3(e): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Sherlett Lake Whitefish

Meristics			Muscle Tissue Metal Levels (ug/g)						
Length (cm)	Weight (g)	Sex (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	T-Cr
40.7	1180	M 4	0.09	0.13	<0.1	0.3	<0.5	<0.5	3.5 <0.5

APPENDIX 3(f): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Sherlett Lake Burbot

Meristics			Muscle Tissue Metal Levels (ug/g)						
Length (cm)	Weight (g)	Sex (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	T-Cr
52.0	1320	M 7	0.19	0.04	<0.1	0.4	<0.5	<0.5	6.2 <0.5
51.0	1100	M 6	0.13	0.04	<0.1	0.4	<0.5	<0.5	7.2 <0.5

APPENDIX 3(g): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Sherlett Lake Perch

Meristics			Muscle Tissue Metal Levels (ug/g)						
Length (cm)	Weight (g)	Sex (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	T-Cr
23.2	200	F 7	0.06	0.01	<0.1	0.2	<0.5	<0.5	4.3 <0.5
23.3	180	M 9	0.17	<0.01	<0.1	0.3	<0.5	<0.5	4.7 <0.5

APPENDIX 4(a): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Cold Lake Northern Pike

Meristics				Muscle Tissue Metal Levels (ug/g)							
Length (cm)	Weight (g)	Sex	Age (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
57.8	1320	F	7	0.17	0.02	<0.1	0.5	0.8	<0.5	5.7	<0.5
66.8	1560	F	10	0.24	0.02	<0.1	0.5	0.8	<0.5	6.9	<0.5
61.0	1360	M	9	0.35	0.02	<0.1	0.9	<0.5	<0.5	5.2	<0.5
57.0	1540	M	6	0.19	0.02	<0.1	0.3	0.8	<0.5	10.9	<0.5
51.7	960	F	5	0.28	0.02	<0.1	0.6	0.8	<0.5	4.9	<0.5
48.0	770	F	8	0.15	0.02	<0.1	0.5	0.8	<0.5	4.8	<0.5
47.5	660	M	7	0.13	0.02	<0.1	0.5	<0.5	<0.5	4.9	<0.5

APPENDIX 4(b): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Cold Lake Common Sucker

Meristics				Muscle Tissue Metal Levels (ug/g)							
Length (cm)	Weight (g)	Sex	Age (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
40.1	900	F	7	0.03	<0.01	<0.1	1.4	1.7	<0.5	4.9	<0.5
39.2	900	F	9	0.08	0.01	<0.1	0.7	<0.5	<0.5	4.2	<0.5
40.5	890	F	12	0.07	<0.01	<0.1	0.7	0.8	<0.5	4.3	<0.5
36.4	720	M	11	0.03	<0.01	<0.1	0.9	<0.5	<0.5	6.2	<0.5
39.0	770	F	10	0.04	<0.01	<0.1	0.5	<0.5	<0.5	5.1	<0.5
40.3	910	F	11	0.04	<0.01	<0.1	0.2	<0.5	<0.5	3.9	<0.5
38.6	790	F	9	0.02	<0.01	<0.1	0.7	<0.5	<0.5	4.3	<0.5
37.8	750	F	6	0.03	0.02	<0.1	0.5	<0.5	<0.5	4.3	<0.5
39.5	820	F	10	0.05	<0.01	<0.1	0.5	<0.5	<0.5	4.3	<0.5
36.8	680	F	9	0.07	<0.01	<0.1	0.2	<0.5	<0.5	3.8	<0.5
35.3	640	F	7	0.02	<0.01	<0.1	0.3	<0.5	<0.5	6.2	<0.5
41.7	920	F	11	0.06	<0.01	<0.1	0.5	0.8	<0.5	3.8	<0.5
36.7	720	M	8	0.04	0.02	<0.1	0.2	0.8	<0.5	2.9	<0.5
37.7	660	M	10	0.04	<0.01	<0.1	0.5	0.8	<0.5	4.4	<0.5
37.6	710	F	6	0.02	<0.01	<0.1	0.5	<0.5	<0.5	3.9	<0.5
37.2	760	F	6	0.02	<0.01	<0.1	0.2	<0.5	<0.5	3.9	<0.5
33.8	540	F	6	0.02	<0.01	<0.1	0.2	<0.5	<0.5	3.6	<0.5
38.5	780	F	6	0.02	0.01	<0.1	0.5	<0.5	<0.5	3.9	<0.5
35.7	650	F	7	0.02	<0.01	<0.1	1.1	<0.5	<0.5	5.1	<0.5
37.4	720	M	10	0.04	0.01	<0.1	0.5	<0.5	<0.5	3.6	<0.5

APPENDIX 4(c): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Cold Lake Walleye

Meristics			Muscle Tissue Metal Levels (ug/g)							
Length (cm)	Weight (g)	Sex (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
36.0	600	M	5	0.05	0.02	<0.1	0.2	<0.5	3.8	<0.5
50.2	1560	F	8	0.19	0.02	<0.1	0.3	<0.5	6.1	<0.5
45.2	1150	F	6	0.16	0.01	<0.1	0.5	0.8	8.6	<0.5
41.0	760	F	6	0.14	<0.01	<0.1	0.2	<0.5	4.3	<0.5
38.8	660	M	5	0.14	0.02	<0.1	0.2	<0.5	4.4	<0.5
37.5	600	M	5	0.15	0.02	<0.1	0.2	<0.5	4.3	<0.5
40.0	760	M	6	0.11	0.01	<0.1	0.2	<0.5	4.4	<0.5
43.5	900	M	6	0.16	0.04	<0.1	0.7	<0.5	6.4	<0.5
43.2	850	M	6	0.17	<0.01	<0.1	0.5	<0.5	5.6	<0.5

APPENDIX 4(d): General Meristics and Muscle Tissue Metal Concentrations (ug/g);
Cold Lake Cisco

Meristics			Muscle Tissue Metal Levels (ug/g)								
Length (cm)	Weight (g)	Sex	Age (Yrs)	Hg (Wet)	As	Cd	Cu	Pb	Ni	Zn	T-Cr
33.3	500	M	7	0.04	0.03	<0.1	0.5	0.8	<0.5	4.2	<0.5
33.6	520	M	9	0.22	0.03	<0.1	0.7	<0.5	<0.5	4.8	<0.5

APPENDIX 5: Net Set Results for Sherlett and Cold Lakes, 1982.

LAKE	TIME DATE SET	TIME DATE LIFTED	LOCATION ¹	NORTHERN PIKE	COMMON SUCKER	WALLEYE	CISCO	WHITEFISH	BURBOT	TOTAL ²
Sherlett	15:00 hrs. 82 06 17	9:00 hrs. 82 06 18	Station #3, NE to shore	1	4	4	65	-	1	75
Sherlett	15:30 hrs. 82 06 17	10:30 hrs. 82 06 18	Station #13, to south	-	4	2	66	1	1	74
Sherlett	13:00 hrs. 82 06 18	9:00 hrs. 82 06 19	Reef, midway from Stations #11 and #14	6	13	1	27	-	-	47
Sherlett TOTAL	-	58 hrs.	274.2 m of net	7	21	7	158	1	2	196
Cold	15:00 hrs. 82 06 21	9:00 hrs. 82 06 22	Reef, 0.75 km north of Station #41	1	3	1	-	-	-	5
Cold	15:30 hrs. 82 06 21	9:30 hrs. 82 06 22	Island, 1.0 km north of Station #41	1	4	3	-	-	-	8
Cold	10:00 hrs. 82 06 22	11:00 hrs. 82 06 23	Bay, 1.5 km NNW of Station #41	1	13	4	1	-	-	19
Cold	10:30 hrs. 82 06 22	11:30 hrs. 82 06 23	Bay, 1.5 km NNW of Station #41	1	19	1	1	-	-	22
Cold TOTAL	-	82 hrs.	365.6 m of net	4	39	9	2	-	-	54

(1) Net set consisted of 45.7 m x 95 mm mesh x 4.9 m deep plus 45.7 m x 108 mm mesh x 3.7 m deep.

(2) The total Sherlett Lake catch was supplemented by angling (6 hrs.) which yielded 13 northern pike, 1 walleye and 2 yellow perch. The total Cold Lake catch was supplemented by angling (17 hrs) which yielded 3 northern pike.

POOR

QUALITY

ORIGINAL